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# Transactions of the American Society for Steel Treating

Vol. XIII March, 1928 No. 3


## FEATURES


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# AGATHON ALLOY STEELS

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RAY T. BAYLESS, *Editor*

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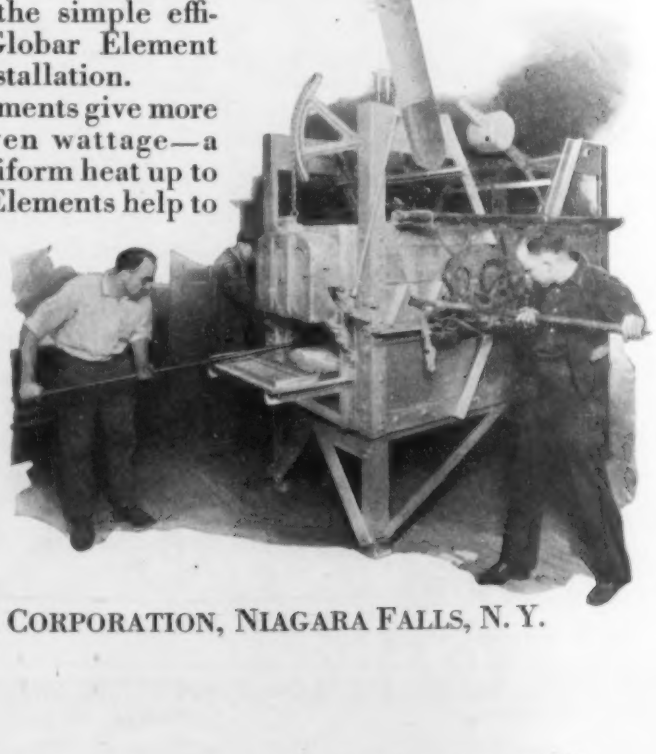

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VOL. XIII MARCH, 1928 NO. 3

# "A CONTRIBUTION TO THE THEORY OF HARDENING AND THE CONSTITUTION OF STEEL"

By Dr. Zay Jeffries

*Abstract*

*In this lecture a brief account of the life and work of Edward DeMille Campbell is given, followed by an abstract from one of his important papers bearing the same title as this lecture.*

*The conclusions are adopted that carbon steel austenite is gamma iron containing carbon in atomic dispersion; that freshly formed carbon steel martensite is alpha iron containing the carbon largely in atomic dispersion; that carbon steel martensite aged at room temperature or somewhat above contains myriads of particles of iron carbide. It is also shown that when acicular martensite forms the orientations of the new alpha iron grains have some relation to the orientation of the parent austenite. After concluding that the hardness of martensite can be attributed to grain refinement and carbon in solid solution, some researches are suggested which should help in estimating to what extent each of these factors contribute to the hardness of freshly formed martensite. "Aged" high carbon steel martensites, containing precipitated carbide, are harder than freshly formed martensites from the same steels.*

IN 1920 Edward DeMille Campbell, Professor of Chemistry and Director of the Chemical Laboratory of the University of Michigan, became a charter member of the Detroit Chapter of the

This paper is the second Edward DeMille Campbell Memorial Lecture presented before the ninth annual convention of the Society held in Detroit, September 19 to 23, 1927. The author, Dr. Zay Jeffries, is consulting metallurgist for the Aluminum Co. of America, the National Tube Co. and the General Electric Co., Cleveland.

American Society for Steel Treating. In April, 1921, he was elected to honorary membership, being the fourth person to receive this distinction. He died on September 18, 1925. On December 5, 1925, the American Society for Steel Treating, seeking to commemorate his achievements, established the E. D. Campbell Lecture. The first E. D. Campbell Lecture was given in Chicago a year ago by Dr. William Minot Guertler of Charlottenburg, Germany, and it is my privilege to present the second.

Professor Campbell was born in Detroit, September 9, 1863. He attended the Detroit public schools and later attended the University of Michigan, graduating in 1886. After four years' work in the field as metallurgical chemist, he returned to the University of Michigan as Assistant Professor of Metallurgy.

According to Professor A. H. White,[1] "he remained at the University of Michigan from 1890 until his death. The growth in numbers of students and staff, with consequent differentiation in duties, brought about various changes in his titles. He organized the course in Chemical Engineering in 1902, and held that professorship among his other titles for twelve years, and was director of the Chemical Laboratory from 1905 until his death."

It is my good fortune to be associated with a number of Professor Campbell's former students and to number many more among my friends. Without exception they admired and loved him; they feel deeply indebted to him for the personal interest which he showed in their work and their lives. The training which he gave them has been no small factor in their fitness for important positions which they hold, not only in chemical and metallurgical work, but as executives and public benefactors. There is universal agreement that, as an educator, Professor Campbell stood in the front rank.

In addition to his administrative and teaching work, he was a tireless experimenter. He published about eighty papers on chemical and metallurgical subjects. Fourteen of the papers dealt with the constitution of Portland cement, and the others with the analysis and constitution of steel. In order to give an idea of the scope of his work on steel, a number of titles and references to his papers, arranged chronologically, are listed below.

REMARKS IN THE DISCUSSION OF THE PHYSICS OF STEEL. *Transactions*, American Institute of Mining Engineers, Vol. 23, p. 620 (1893).

[1] *Industrial and Engineering Chemistry*, No. 11, Vol. 17, p. 1204.

DETERMINATION OF NICKEL IN NICKEL STEEL. *Journal*, American Chemical Society, Vol. 16, p. 96 (1894).

DETERMINATION OF NICKEL IN NICKEL STEEL. *Journal*, American Chemical Society, Vol. 17, p. 125 (1895).

SEPARATION OF NICKEL AND IRON. *Journal*, American Chemical Society, Vol. 17, p. 164 (1895).

A PROPOSED SCHEDULE OF ALLOWABLE DIFFERENCES AND OF PROBABLE LIMITS OF ACCURACY IN QUANTITATIVE ANALYSES OF METALLURGICAL MATERIALS. *Journal*, American Chemical Society, Vol. 18, p. 35 (1896).

ON THE DIFFUSION OF SULPHIDES THROUGH STEEL. *Journal*, American Chemical Society, Vol. 18, p. 707 (1896).

ON THE INFLUENCE OF HEAT TREATMENT AND CARBON UPON THE SOLUBILITY OF PHOSPHORUS IN STEELS. *Journal*, American Chemical Society, Vol. 18, p. 719 (1896).

A PURE CARBIDE OF IRON. *Journal*, American Chemical Society, Vol. 18, p. 836 (1896).

REMARKS IN THE DISCUSSION OF SAUVEUR'S PAPER ON THE MICROSTRUCTURE OF STEEL AND THEORIES OF HARDENING. *Transactions*, American Institute of Mining Engineers, Vol. 27, p. 869 (1897).

A PRELIMINARY THERMOCHEMICAL STUDY OF IRON AND STEEL. *Journal*, American Chemical Society, Vol. 19, p. 754 (1897).

FURTHER STUDY OF THE INFLUENCE OF HEAT TREATMENT AND CARBON UPON THE SOLUBILITY OF PHOSPHORUS IN STEEL. *Journal*, American Chemical Society, Vol. 19, p. 786 (1897).

ON THE INFLUENCE OF SILICON UPON THE HEAT OF SOLUTION OF COKE CAST IRONS. *Journal*, American Chemical Society, Vol. 20, p. 690 (1898).

ON THE DIFFUSION OF SULPHIDES THROUGH STEEL. *Journal*, Iron and Steel Institute, Vol. 54, p. 256 (1898).

THE CONSTITUTION OF STEEL. *Journal*, Iron and Steel Institute, Vol. 56, p. 223 (1899).

THE HEAT OF FORMATION OF CARBIDES AND SILICIDES OF IRON. *Journal*, Iron and Steel Institute, Vol. 59, p. 211 (1901).

PROBABLE EXISTENCE OF A NEW CARBIDE OF IRON $Fe_2C$. *Journal*, Iron and Steel Institute No. 2, E. D. Campbell and M. B. Kennedy (1902).

SOME FURTHER EXPERIMENTS ON THE DIFFUSION OF SULPHIDE THROUGH STEEL. *Journal*, Iron and Steel Institute (1903).

NOTE ON THE OCCURRENCE OF COPPER, COBALT, AND NICKEL IN AMERICAN PIG IRONS. *Journal*, Iron and Steel Institute, No. 2 (1905).

DETERMINATION OF NICKEL AND CHROMIUM IN STEEL. *Journal*, American Chemical Society, Vol. 30, No. 7 (1908).

A NEW METHOD FOR THE DETERMINATION OF VANADIUM IN IRON AND STEEL. *Journal*, American Chemical Society, Vol. 30, No. 8, E. D. Campbell and E. L. Woodhams (1908).

THE CONSTITUTION OF CARBON STEELS. *Journal*, Iron and Steel Institute, No. 3, p. 318 (1908).

ON THE DECOMPOSITION OF METHYLENE, IODIDE AND ITS BEARING ON THE CONSTITUTION OF STEEL. *Journal*, American Chemical Society, Vol. 34, p. 1159 (1912).

THE EFFECT OF HEAT TREATMENT ON THE COLORIMETRIC TEST FOR CARBON IN A 0.32 PER CENT CARBON STEEL. *Journal*, Iron and Steel Institute, No. 2, p. 367, E. D. Campbell, and F. D. Haskins (1913).

A CONTRIBUTION TO THE THEORY OF HARDENING AND THE CONSTITUTION OF STEEL. *Journal*, Iron and Steel Institute, No. 2 (1914).

ON THE INFLUENCE OF HEAT TREATMENT ON THE SPECIFIC RESISTANCE AND CHEMICAL CONSTITUTION OF CARBON STEELS. *Journal*, Iron and Steel Institute, No. 2 (1915).

CAN THE DISSOCIATION THEORY BE APPLIED TO SOLID SOLUTIONS IN STEELS? *Journal*, American Chemical Society, Vol. 37, No. 9 (1915).

THE INFLUENCE OF HEAT TREATMENT ON THE THERMOELECTRIC PROPERTIES

AND SPECIFIC RESISTANCE OF CARBON STEELS. *Journal*, Iron and Steel Institute, No. 2, p. 268 (1916).

DO EQUIATOMIC SOLUTIONS IN IRON POSSESS EQUAL RESISTANCES? *Transactions*, Faraday Society, Vol. 12 (1917).

INFLUENCE OF TEMPERATURE OF MEASUREMENT ON THE ELECTRICAL RESISTIVITY AND THERMOELECTROMOTIVE POTENTIAL OF SOLUTES IN STEELS. *Transactions*, American Electrochemical Society, Vol. 32, p. 103 (1917).

THE INFLUENCE OF HEAT TREATMENT ON THE ELECTRICAL AND THERMAL RESISTIVITY AND THERMOELECTRIC POTENTIAL OF SOME STEELS. *Journal*, Iron and Steel Institute, No. 2, p. 251, E. D. Campbell and W. C. Dowd (1917).

ON THE RATE OF CHANGE AT 100 DEGREES CENT. AND AT ORDINARY TEMPERATURES IN THE ELECTRICAL RESISTANCE OF HARDENED STEEL. *Journal*, Iron and Steel Institute, No. 2, p. 421 (1918).

ON THE DECARBURIZATION OF STEEL WITH HYDROGEN. *Journal*, Iron and Steel Institute, No. 2, p. 407 (1919).

THE SOLUTION THEORY OF STEEL AND THE INFLUENCE OF CHANGES IN CARBIDE CONCENTRATION ON THE ELECTRICAL RESISTIVITY. *Transactions*, Faraday Society, Read December 15 (1919).

NOTES AS TO RATES OF REACTION IN CERTAIN STEELS AT 930 DEGREES CENT. *Journal*, Iron and Steel Institute, Vol. 102, No. 2, p. 281, E. D. Campbell, and B. A. Soule (1920).

A FORCE FIELD DISSOCIATION THEORY OF SOLUTION APPLIED TO SOME PROPERTIES OF STEEL. *Transactions*, Faraday Society, Vol. 16, part 3 (1921).

SOME BRINELL HARDNESS MEASUREMENTS ON SMALL SPECIMENS. TRANSACTIONS, American Society for Steel Treating, Vol. 2, No. 4, p. 269 (1922).

A PRELIMINARY MAGNETIC STUDY OF SOME HEAT TREATED CARBON STEELS. *Journal*, Iron and Steel Institute, Vol. 106, No. 2, p. 201, E. D. Campbell and E. R. Johnson (1922).

A BRINELL MACHINE ATTACHMENT FOR USE WITH SMALL SPECIMENS. *Journal*, Iron and Steel Institute, Vol. 106, No. 2, p. 193 (1922).

THE RELATIVE EFFICIENCY OF DRY AND OF MOIST HYDROGEN ON THE DECARBURIZATION OF STEEL AT 950 DEGREES CENT., AND THE EFFECT OF HYDROGEN ON THE PHOSPHORUS CONTENT. *Journal*, Iron and Steel Institute, Vol. 108, No. 2, p. 179, E. D. Campbell, J. F. Ross and W. L. Fink (1923).

THE IRON-IRON CARBIDE EQUILIBRIUM IN DRY HYDROGEN AT 950 DEGREES CENT. *Journal*, Iron and Steel Institute, Vol. 108, No. 2, p. 173, E. D. Campbell, W. L. Fink and J. F. Ross (1923).

THE EFFECT OF CHANGES IN TOTAL CARBON AND IN THE CONDITION OF CARBIDES ON THE MAGNETIC PROPERTIES OF STEEL. *Physical Review*, Vol. 23, p. 377, A. W. Smith, E. D. Campbell and W. L. Fink (1924).

A LABORATORY METHOD FOR THE PREPARATION OF SMALL STEEL BARS DIFFERING ONLY IN CARBON CONTENT AND THE EFFECT OF CHANGES IN CARBIDE CONCENTRATION ON THE SPECIFIC RESISTANCE. TRANSACTIONS, American Society for Steel Treating, January, p. 33, E. D. Campbell and G. W. Whitney (1924).

THE EFFECT OF CHANGES IN TOTAL CARBON AND IN THE CONDITION OF CARBIDES ON THE SPECIFIC RESISTANCE AND ON SOME MAGNETIC PROPERTIES OF STEEL. *Journal*, Iron and Steel Institute, Vol. 110, No. 2, p. 291, E. D. Campbell and G. W. Whitney (1924).

A STUDY OF THE CORRELATION OF THE REMANENT MAGNETISM AND SPECIFIC RESISTANCE OF SOME PURE IRON-CARBON ALLOYS. *Transactions*, Faraday Society, Vol. 21, No. 63 (1925).

THE CHROMIUM-IRON EQUILIBRIUM IN CARBIDES RECOVERED FROM ANNEALED 2.23 PER CENT CHROMIUM STEELS. *Journal*, Iron and Steel Institute, Vol. 112, No. 2, p. 255, E. D. Campbell and J. F. Ross (1925).

INFLUENCE OF HEAT TREATMENT AND CARBON CONTENT ON THE STRUCTURE OF PURE IRON CARBON ALLOYS. TRANSACTIONS, American Society for Steel Treating, Vol. 9, p. 717, W. L. Fink and E. D. Campbell (1926).

THE SPECIFIC RESISTANCE AND THERMOELECTROMOTIVE POTENTIAL OF SOME STEELS DIFFERING ONLY IN CARBON CONTENT. *Journal*, Iron and Steel Institute, Vol. 63, No. 1, p. 375, E. D. Campbell and H. W. Mohr (1926).

From the time of his graduation, Professor Campbell was interested in the nature of steel. In the spring of 1892 he was conducting some experiments on the nature of the hydrocarbon gases evolved on solution of steel which had been subjected to various heat treatments. A hydrogen explosion occurred one day when he was examining the apparatus closely, and permanently blinded him.

Professor Campbell's accomplishments either as administrator and teacher or as an experimenter would be a creditable achievement for one in possession of all of his senses; for one totally blind to have achieved both seems almost unbelievable. As an illustration of his unabated activity in research, the last three papers listed above were read at meetings of technical societies after his death.

It is apparent from a study of Professor Campbell's publications that he was most interested in the nature and constitution of steel and more particularly of hardened steel. In a paper presented before the Iron and Steel Institute of Great Britain in 1914, entitled "A Contribution to the Theory of Hardening and the Constitution of Steel", Professor Campbell summarized his views as follows:

"The working hypothesis which has served the purpose of training students, and as a basis for systematic experimental work in this laboratory for upwards of twenty years, but for which comparatively little originality is claimed, is a composite conception, including as many of the ideas of previous experiments as seemed necessary to furnish a reasonable explanation of the known facts concerning the behavior of steel. This hypothesis assumes that the chemical constitution of steel is the most important single factor in determining the mechanical properties, since the nature and extent of the changes in the mechanical properties induced by different rates of cooling from different temperatures will fundamentally rest on the chemical constitution of the mass at the instant of quenching.

"The chemical constitution of steel is regarded as a study in solubilities, the perfect parallelism between the solution of substances in iron as a solvent and that of ordinary substances in

aqueous solution so clearly pointed out by Langley[2] being recognized. Langley considered the iron as a solvent but did not include the allotropy of iron or the molecular constitution of carbides in his conceptions.

"The hypothesis now of course assumes that iron is capable of existing in at least two allotropic forms, alpha and gamma, differing somewhat in mechanical properties but most markedly in solvent power, the gamma iron possessing a much greater solvent and dissociating power than iron in the alpha form. There seems to be no necessity for assuming the existence of an intermediate beta form of iron, and the most recent work seems to indicate that no such form exists. We have no knowledge of the molecular weight or molecular constitution of iron in the solid condition, so that we have no positive knowledge of the reason for the differences in properties of alpha and gamma iron; but it is reasonable to assume that these differences are connected with the changes in molecular weight or atomic arrangement within the molecule or both.

"It is well known that in certain isomorphous crystals, such as magnesium sulphate and ferrous sulphate, we may have iron apparently replacing the magnesium atomically in any proportion up to a certain percentage, the crystals retaining the form of the crystals of pure magnesium sulphate, but the other properties being modified by the substitution of iron for magnesium. In a similar way, we have assumed that certain elements, such as nickel and manganese, when added to iron may atomically replace the iron in a complex molecule, thus modifying the physical properties, especially its solvent and dissociating power and its magnetic properties. On what molecular constitution ferro-magnetism depends we are unable to say, but so far as we know there is no instance on record in which iron has been rendered non-magnetic at ordinary temperatures without the addition of some other element which might atomically replace part of the iron, and in this way modify the molecular constitution as compared with that which would exist in strictly pure iron. In this sense it is a proper question to ask whether there is any evidence to show that strictly pure gamma iron would be non-magnetic.

"If then, iron be regarded as a solvent capable of existing in two allotropic forms possessed of marked differences in sol-

[2] *Proceedings*, American Society of Civil Engineers, Vol. 27, p. 682.

vent and dissociating power and capable of being replaced atomically by other elements, this atomic substitution often profoundly modifying the properties of the solvent, the next natural thing to consider would be the chemical constitution of the solutes.

"Although the carbon compounds in steel are by far the most important of the solutes, yet the general conception of steel as a study in solubilities would apply just as much to compounds of other elements with iron as to the carbon compounds. It has been known for nearly a century that when steel is dissolved in acids various compounds of carbon and hydrogen are evolved, and at least fifty years ago research work in both Germany and France seemed to demonstrate the existence of a good many different carbides of iron. In 1877 Cloëx[3] undertook some extensive work in the way of studying hydrocarbons obtained by dissolving manganiferous iron, but apparently drew no conclusions from his results. It was in 1885 that Sir F. Abel[4] described the recovery of a pure carbide of iron from annealed steel and assigned to it the formula $Fe_3C$, this formula being based wholly on the percentage of carbon and iron. As it is impossible for a chemist to account for all the products of solution of the carbides of iron if so simple a formula as $Fe_3C$ is employed to represent these, the writer undertook research work on a study of the products of solution of steel, about 1891, to see whether any relations existed between the carbon concentration and heat treatment of steel and the products of solution. In the development of this work it has been shown[5] that in annealed steel the mean molecular weight of the hydrocarbons evolved, hence, presumably, of the carbides from which the hydrocarbons are derived, decreases as the percentage of carbon increases, that is, the carbides existing in hypereutectoid steel have a lower molecular weight than in hypoeutectoid metal. Second, that with a given steel the mean molecular weight of the hydrocarbons evolved from hardened steel is lower than that of hydrocarbons from the same steel annealed, that is, the molecular weight of the carbides decreases when the metal is hardened. More recently[6], in another paper it has been shown by a study of the dinitro-derivatives derived from the carbides in steel that the car-

[3] *Comptes Rendus*, Vol. 85, p. 1003.

[4] *Proceedings*, Institution of Mechanical Engineers, 1885, p. 30.

[5] *Journal*, Iron and Steel Institute, 1899, No. 5, p. 223.

[6] *Journal*, Iron and Steel Institute, 1913, No. 2, p. 367.

bides of lower molecular weight are more readily soluble in iron than those of higher molecular weight and have a greater hardening effect, but that they tend to dissociate with rising temperature, probably a dissociation analogous to ionic dissociation in liquid solutions, for which dissociation the author ventures to suggest the term 'ionoid.' It was also shown that carbides of high molecular weight with rising temperature tend to split up into compounds of lower molecular weight and undergo more or less ionic dissociation. . . .

"The simple assumption that the carbides in steel are to be regarded as metallic substitution products of the hydrocarbons, whose molecular weights and molecular constitutions will depend upon the carbon concentration and heat treatment, offers a reasonable explanation for all the products of solution, and opens up an almost unlimited field for research on the constitution of these carbides."

Much of Professor Campbell's experimental work was directed toward the proof or disproof of the above hypothesis regarding the condition of the carbon in steel. Chemists find a way to explain the evolution of the various hydrocarbon gases without resorting to complex molecules of iron carbide. Furthermore, Professor Campbell's views as to the complex nature of the carbides have never been widely accepted by metallurgists. But he was always careful to separate fact from theory and he never compromised what appeared to him to be a fact. In addition to his own theories, therefore, he has given us many new facts which are useful in the arts and which will be helpful in the formulation of any hypothesis which can stand the test of time.

It must be remembered that the above statement was made thirteen years ago before the advent of the X-ray information on the crystal structure of iron and steel and without access to many other researches now available. Yet it would be difficult today to make a better statement of many of the points than is contained in his 1914 summary. Particularly noteworthy and prophetic are his statements regarding beta iron and his suggestion that such elements as nickel and manganese substitute for iron atoms when in solid solution in iron.

Because Professor Campbell made the study of the nature of steel the chief research activity of his life, and because he was most interested in the constitution and cause of hardness of hard-

ened steel, it seems fitting to discuss this subject further today. I have, therefore, selected as the title of this lecture the title of his 1914 Iron and Steel Institute paper. This subject is one on which much work has been done and on which much has been written. It is so fundamental to the art and science of steel treating that no apology is offered for discussing it further today.

## Hardening and Constitution of Steel Discussion

If we were certain of the constitution of martensite we might still be in doubt as to the cause of its hardness. The problem would, however, be much simplified. For example, if we were certain that martensite is a solid solution of carbon in alpha iron, we would not know whether its hardness were due chiefly to solid solution, grain refinement, or other causes which have been postulated. We could, however, exclude hardening by fine dispersion of hard particles or hardening by the presence of hard particles. If, on the other hand, we knew the precise manner by which the mechanism of slip is interfered with in hard martensite, we would then know its constitution.

It is almost the universal opinion that austenite in carbon steel is carbon or iron carbide dissolved in gamma iron. Many of those who believe that the carbon is present in austenite as iron carbide believe that carbon diffuses as carbon atoms rather than as iron carbide molecules. That molecules of $Fe_3C$ as such would find it difficult to diffuse in solid iron seems reasonable. Furthermore, since the work of Sykes[7] on the iron-tungsten system, it appears that tungsten is able to diffuse in iron at about the same temperature regardless of the molecular formula of the compound in equilibrium with the iron-rich solid solution. In carbon-free iron-tungsten alloys the compound is $Fe_3W_2$ according to Sykes, and in high speed steel it is $Fe_4W_2C$ according to Westgren and Phragmen.[8] In the latter compound chromium or vanadium may substitute for part of the iron or tungsten. It does not seem consistent with our knowledge regarding atomic forces and dimensions of space lattices for a complex compound like $Fe_4W_2C$ to diffuse through the iron space lattice at 1100 degrees Fahr. (600 degrees Cent.). If these compounds must dissociate in order

[7] *Transactions*, American Institute of Mining and Metallurgical Engineers, Vol. 73, 1926, p. 968.

[8] American Society for Steel Treating, Ninth Annual Convention, Detroit, September, 1927.

to permit diffusion why not assume that they are dissociated when in solid solution? Westgren[9] not only holds that the carbon in austenite is present as carbon atoms but from experimental evidence, confirmed by Harder and Dowdell,[10] he concludes that the carbon atoms occupy positions in between the space lattice points of gamma iron. Professor Campbell considered the carbon in austenite to be present largely as carbon "ionoids". The term ionoid as coined and defined by Professor Campbell means an atom whether ionized or not. For the purposes of our discussion we will assume that carbon steel austenite is gamma iron in which carbon atoms are atomically dispersed.

It is the universal opinion that when carbon steel austenite cools slowly from above the critical temperature range it transforms into alpha iron and the iron carbide $Fe_3C$ called cementite. Based on our assumption of the constitution of austenite alpha iron forms by atomic rearrangement of iron atoms from the face-centered to the body-centered cubic space lattice. The carbide is supposed to form from carbon and iron atoms, the formation and crystallization into cementite probably being simultaneous.

The carbide formation requires diffusion of the carbon atoms and hence a certain amount of time is required for the reaction to be completed. The allotropic transformation of the iron does not require diffusion and hence this change should be capable of taking place more rapidly than the formation of cementite, especially at low temperatures. Thus it is that carbon steel can be cooled so rapidly through the normal transformation range [between 1290 and 1200 degrees Fahr. (700 and 650 degrees Cent.)] that the carbide cannot form. Under these conditions, especially when considerable carbon is present, the austenite cools to a temperature of 570-390 degrees Fahr. (300-200 degrees Cent.) apparently unchanged. At some temperature, far below the equilibrium temperature for alpha iron and cementite to form, the transformation begins producing martensite. If a piece of medium or high carbon steel is cooled rapidly from the temperature at which martensite begins to form, without interruption to or below room temperature, it appears that very little carbide is precipitated. This conclusion is based in part on the fact that the change from gamma to alpha iron is accompanied by expansion

[9] *Journal*, Iron and Steel Institute, Vol. 104, No. 1, 1924, p. 159.

[10] TRANSACTIONS, American Society for Steel Treating, Vol. 11, 1927, p. 973.

and formation of carbide is accompanied by contraction in volume. When martensite forms the expansion takes place commensurate with that of the allotropic transformation and the contraction which should accompany carbide formation and growth of the carbide particles takes place gradually during reheating. This is evidence that the carbide is not precipitated during quench-

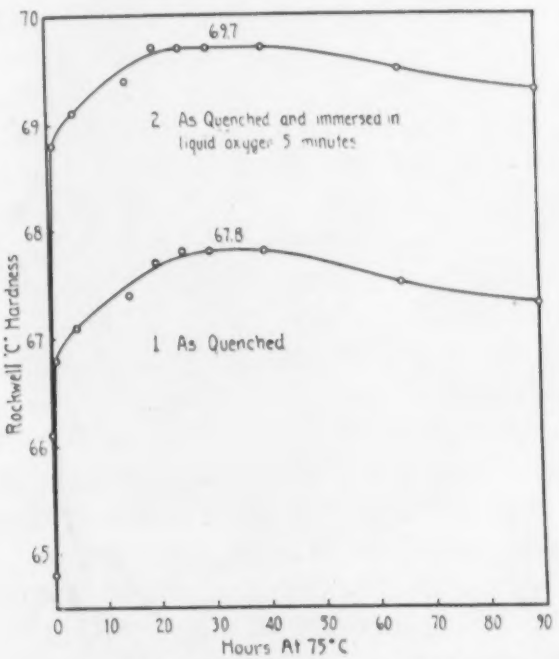


**Fig. 1—Steel Containing 1.23 Per Cent Carbon, Quenched from 1560 Degrees Fahr. (850 Degrees Cent.) and Aged at 165 Degrees Fahr. (75 Degrees Cent.). Sykes and Jeffries.**

ing. This conclusion is much strengthened by the recent work of Sykes and the writer,[11] showing that freshly formed martensite obeys the laws of precipitation hardening. Fig. 1 shows that heating a high carbon steel for a few minutes at 165 degrees Fahr. (75 degrees Cent.) produces a substantial hardness increase and that the hardness increases much more slowly with time, indicating that the aging effect at the beginning was in its infancy.

Furthermore, the formation of martensite in high carbon steel seems to be quite analogous to the formation of martensite in carbon-free iron-nickel alloys. The transformation takes place over a range of temperature during cooling and an acicular or

[11]American Society for Steel Treating, Ninth Annual Convention, Detroit, September, 1927.

needle-like structure is produced. In certain of the iron-nickel alloys the assumption is that the transformation is from a solid solution of nickel in gamma iron to a solid solution of nickel in alpha iron. Similarly the formation of martensite in carbon steel would be regarded as the transformation of a solid solution of carbon in gamma iron to a solid solution of carbon in alpha iron. The constitution of freshly formed carbon steel martensite therefore appears to be a solid solution of carbon in alpha iron.

In making this statement it is contemplated that, following the lead of Dr. John A. Mathews, retained austenite should be called austenite, that alpha iron precipitated at grain boundaries of the austenite should be referred to as ferrite and carbide particles existing as such at the time of quenching should be referred to as cementite or other carbide. It is quite probable that a small amount of carbide precipitates from the martensite after its formation but during cooling. Heating freshly quenched high carbon steel for one minute at 100 degrees Cent. produces a measureable increase in hardness, indicating the rapidity with which carbide precipitates at that temperature. The hardness increase is measureable after 15 minutes' aging at room temperature, showing that the constitution of so-called "freshly formed" martensite is not permanent at room temperature. Apparently a temperature slightly below 0 degree Cent. is required to preserve the "as quenched" constitution of martensite.

The constitution of ordinary martensite, aged at room temperature or slightly above appears to be alpha iron still containing some carbon in solution plus minute particles of iron carbide.

In a cold-worked pure metal the constitution is known but much remains to be learned about its ultimate structure. Also we might know the constitution of martensite without knowing the shapes, sizes and orientations of its grains. What is known as typical martensite has a characteristic needle or acicular structure. The needles are known to be parallel with the octahedral or 1 1 1 planes of the austenite grains which gave birth to the martensite. These are also the planes of easiest slip in the austenite.

The origin of the acicular structure would seem to be a natural consequence of the constitution of martensite postulated above. When hypoeutectoid steel cools slowly through the critical range the excess ferrite is precipitated first from the austenite. It precipitates with a first preference at the austenite grain boun-

daries and a second preference in or parallel to the octahedral planes of the austenite. When a hypereutectoid steel cools slowly through the critical range the excess cementite is precipitated with a first preference at the austenite grain boundaries and a second preference in or parallel to the octahedral planes of the

Fig. 2—Alloy Containing 78 Per Cent Iron and 22 Per Cent Molybdenum Cooled Slowly from 2685 Degrees Fahr. (1475 Degrees Cent.). Shows Separation of $Fe_3Mo_2$ at Grain Boundaries and in 1 1 0 Planes. 250 x. Sykes.

austenite. Precipitation in the octahedral planes is favored by any condition which does not permit diffusion to the grain boundaries as fast as precipitation takes place. Moderately rapid cooling through the temperature range within which diffusion is rapid, large austenite grain size and low temperature of precipitation should therefore favor precipitation in the octahedral planes.

This tendency for new phases separating from solid solutions to precipitate at grain boundaries and on the planes of easiest slip seems to be general. For example, Sykes[12] found that iron molybdide separating from a supersaturated solid solution of molybdenum in alpha iron precipitated at the grain boundaries and in the 1 1 0 planes which are the planes of easiest slip. This is shown in Fig. 2. It was observed in the laboratories of the Aluminum Company of America and reported by Dix and Rich-

[12]Transactions, American Society for Steel Treating, Vol. 10, 1926, p. 839.

ardson[13] that $CuAl_2$ separating from a supersaturated solid solution of copper in aluminum precipitated preferably at grain boundaries and in the octahedral planes.

When two new phases form from a solid simultaneously, however, as when 0.90 per cent carbon austenite transforms to pearlite the crystalline structure of the parent solid solution does not seem to exercise such a controlling influence. Lamellar pearlite for example, born from one crystal of solid solution, seems to have almost the identical structural characteristics of certain eutectics born from liquid solutions.

The acicular structure of martensite, therefore, seems to be due to the precipitation of alpha iron or alpha iron solid solution in the octahedral planes of the mother austenite. The transformation in carbon steel is from a solid solution of carbon in gamma iron to a solid solution of carbon in alpha iron. Only one new crystalline phase is formed, the carbide formation being prevented because the time-temperature conditions do not permit of substantial diffusion of carbon. The low temperature of transformation would account for the precipitation occurring at the places of second choice, namely, at the octahedral planes instead of at grain boundaries.

But it does not account for the acicular structure of martensite to merely say that the alpha iron solid solution separates in the austenite octahedral planes. The new crystals of alpha iron must have larger dimensions parallel to these planes than normal to them. The new crystals must be rod or needle-shaped or what is more probable in many cases at least, platelets with the large surfaces parallel or nearly parallel with the octahedral planes of the austenite. That these planes have powerful directing forces for producing platelets is shown by the separation of cementite platelets from hypereutectoid steel and ferrite platelets from hypoeutectoid steel austenite during slow cooling even though surface tension forces would favor the formation of spheres or some approximately equiaxed shape. At the low temperatures at which the acicular martensitic structures are formed, surface tension forces are not dominating anyway.

The martensitic structure is not unique in the iron-carbon alloys; in fact neither iron nor carbon is necessary for its for-

[13] *Transactions*, American Institute of Mining and Metallurgical Engineers, Vol. 73, 1926, p. 560.

mation. Copper containing about 10 per cent aluminum produces a typical martensitic structure when the face-centered cubic alpha solid solution changes rapidly to the body-centered cubic beta solid solution. Carbon-free iron containing about 20 per cent nickel produces a typical martensitic structure when the face-centered cubic solid solution transforms at a low temperature to the body-cen-

Fig. 3—Slip Bands Near Rockwell Impression in an Alloy Containing 81 Per Cent Iron and 19 Per Cent Nickel. 200 x. Sykes.

tered cubic solid solution. All of these martensitic structures originate from a face-centered cubic solid solution and transform to a body-centered cubic solid solution.

An iron-nickel alloy[14] containing about 20 per cent nickel begins to transform from the gamma to the alpha condition when cooled to about 390 degrees Fahr. (200 degrees Cent.) and the transformation seems to be about complete when room temperature is reached. The structure is typically martensitic in which some of the new grains of alpha iron solid solution may be so large as to be easily visible under the microscope at a magnification of 50 diameters. That the apparent boundaries are real grain boundaries is indicated by Fig. 3 showing slip planes in a 19 per cent nickel alloy in an area adjacent to a Rockwell impression.

[14]Osawa; *Journal*, Iron and Steel Institute, No. 1, 1926, Vol. 113, p. 447.

Bain[15] has offered a theory of the mechanism of the face-centered cubic to the body-centered cubic space lattice transformation. The face-centered cubic lattice of gamma iron can be regarded as a body-centered tetragonal lattice with an axial ratio of 1.41. Bain suggests that the transformation takes place by compressing the long axis and simultaneously expanding the minor

Fig. 4—Originally a Single Crystal of Eutectoid Austenite which Later Transformed Into Lamellar Pearlite. 2 x. Hibbard.

axes of the body-centered tetragonal lattice until the axial ratio is unity, which would result in the body-centered cubic structure of alpha iron. X-ray experiments by Miss E. Chartkoff, A. B. Gladding and the author, throw considerable light on this subject.

Henry D. Hibbard obtained some samples of pearlite known to have formed from one grain of austenite. Fig. 4 is a photograph of one of such pieces magnified 2 diameters. The microscope shows the inner structure to be lamellar pearlite. Fig. 5 is an X-ray crystal pattern of a thin section of one of these specimens. If the alpha iron of the pearlite has been formed by the mechanism suggested by Bain only three orientations will be present. The X-ray shows the presence of many alpha iron orientations in a disk 0.031 inch in diameter and 0.0015 inch in thickness which represents only a fraction of one per cent of the original austenite grain. Also, the orientations are as nearly random as could be expected from the number of alpha iron grains present. The orientation of the ferrite grains of pearlite seem, there-

[15] *Transactions*, American Institute of Mining and Metallurgical Engineers, Vol. 70, 1924, p. 25.

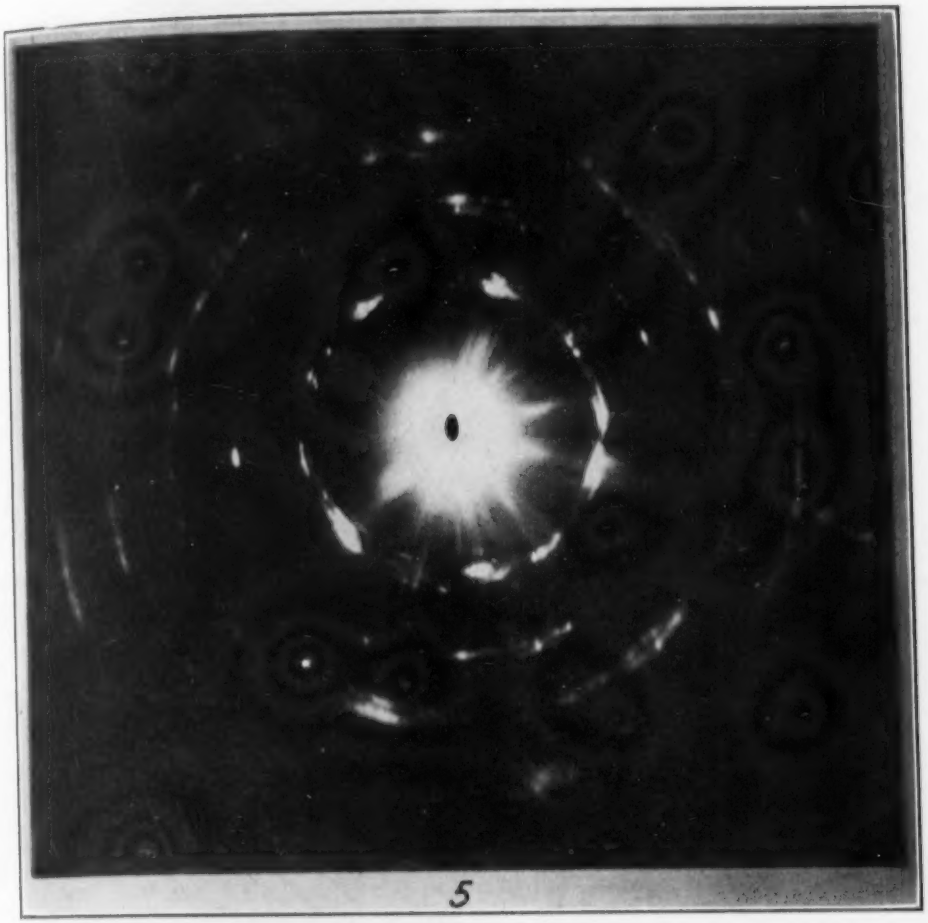


Fig. 5—X-Ray Crystal Pattern of Pearlite from Single Crystal Austenite. Shows Ferrite of Many Orientations. Chartkoff and Gladding.

fore, to have no relation to the orientation of the parent austenite.

John Howe Hall kindly supplied a sample of Hadfield's austenitic manganese steel which was very coarse grained. By microscopic examination an area was segregated which contained only two grains. X-ray crystal patterns were obtained on this area showing only a spot here and there corresponding to the austenite lattice, with no indication of the presence of alpha iron. After heating to 930 degrees Fahr. (500 degrees Cent.) for 60 hours the pattern shown in Fig. 6 was obtained. This shows that all of the austenite has not been transformed but that many grains of alpha iron are present. Because the X-ray photograph was taken by so-called "reflection" from the two original austenite grains rather than by transmission of the X-ray beam through the specimen the alpha iron lines do not form complete circles. These

results show that two austenite grains of manganese steel about 1 millimeter in diameter transform into tens of thousands of alpha iron grains at 930 degrees Fahr. (500 degrees Cent.) and that the orientations of the alpha iron grains are random. The same conclusion may be made with respect to one of these large austenite grains of manganese steel.

In the austenite to pearlite transformation it seems probable

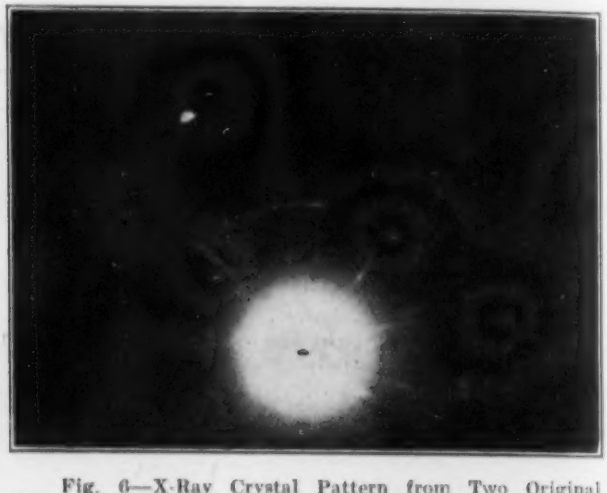

Fig. 6—X-Ray Crystal Pattern from Two Original Grains of Hadfield's Manganese Steel Austenite After Heating 60 Hours at 950 Degrees Fahr. (500 Degrees Cent.). Chartkoff and Gladding.

that the alpha iron and cementite form simultaneously. In the decomposition of manganese steel austenite it is probable that carbide precipitation precedes the allotropic transformation. The precipitation of the carbide from myriads of centers should make the austenite adjacent to each carbide particle less stable because of impoverishment in carbon and hence more susceptible to change to alpha iron. Hence the large number and consequent small size of the alpha iron grains. On the other hand there is a great tendency for alpha iron grain growth at 930 degrees Fahr. (500 degrees Cent.), which is hindered by the presence of carbide in fine dispersion. The narrowness of the alpha iron lines in Fig. 6 would indicate that the alpha iron grains are not small enough to produce wide lines. Clearly then in the formation of pearlite and in the decomposition of austenitic manganese steel to carbide and alpha iron at 930 degrees Fahr. (500 degrees Cent.) the mechanism of the transformation cannot be the "up setting" of the body-centered tetragonal lattice of gamma iron.

Some coarse-grained austenite of steel containing 1.57 per cent carbon was prepared by W. P. Sykes by heating for five days at 1830 to 2010 degrees Fahr. (1000 to 1100 degrees Cent.), followed by heating to 2210 degrees Fahr. (1210 degrees Cent.). The specimen was then cooled to 1470 degrees Fahr. (800 degrees Cent.) in air, so as to mark the austenite grain boundaries by the excess cementite net work, and was quenched from this temperature. Martensite from very large grains of austenite was thus formed, of course, mixed with some retained austenite. Thin sections were prepared, so that X-ray crystal patterns could be obtained from one or at most two or three original austenite grains. The few spots of the gamma iron lattice confirmed the microscopic evidence as to the coarseness of the austenite grains.

Fig. 7 shows one of the crystal patterns. It is clear that all orientations are not equally represented and in fact certain orientations appear to be definitely absent. Figs. 8 and 9 of similar specimens tempered at 570 and 930 degrees Fahr. (300 and 500 degrees Cent.) for 1 hour show the same characteristics, except that no austenite remains. In Fig. 9 it seems clear that each spot is caused by many small grains similarly oriented. This conclusion is based on the irregularity of the boundaries of the spots and their regular arrangement. Fig. 10 is an X-ray crystal pattern of a 1.00 per cent carbon steel quenched from 2190 degrees Fahr., showing the same characteristics as the 1.57 per cent carbon steel.

There are far too many orientations present to be accounted for by the up-setting mechanism of transformation. While too little evidence is yet available to draw definite conclusions it appears that the preferred orientations in the alpha iron grains of the martensite can be accounted for by assuming that those orientations are most prevalent which permit of most rapid growth of the alpha iron in directions parallel with the octahedral planes of the austenite. Desch[16] in reporting the work of others states that the velocity of growth of a crystal is greatest in directions normal to planes of low atomic density. Because the temperature of formation of martensite is low it seems logical that the velocity of growth of the grains at the time of their formation should play some part in determining which nuclei should persist, as-

[16] *Proceedings*, Institute of Metals Division, American Institute of Mining and Metallurgical Engineers, 1927, p. 13.

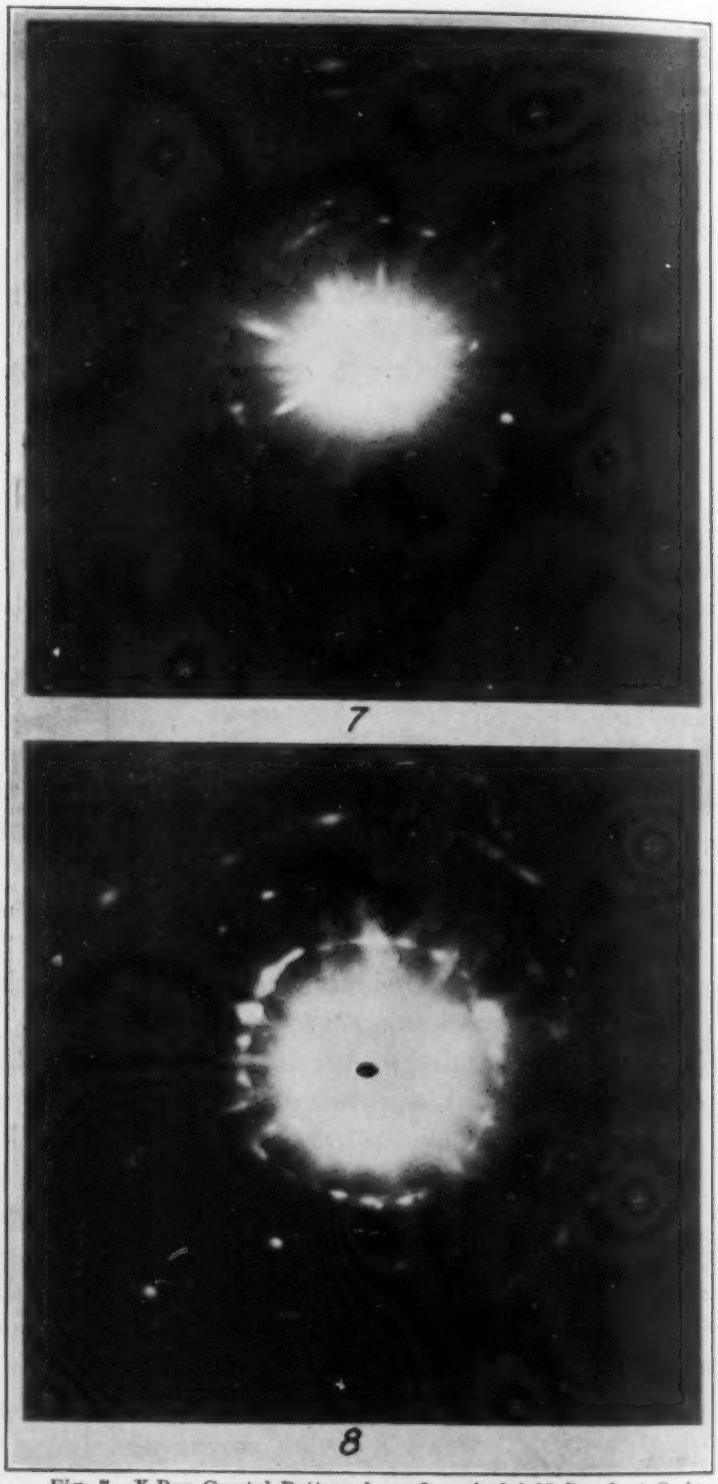


Fig. 7—X-Ray Crystal Pattern from Quenched 1.57 Per Cent Carbon Steel. Steel was Composed of Large Grains of Austenite at Time of Quenching. Chartkoff and Gladding. Fig. 8—X-Ray Crystal Pattern of Same Specimen as Fig. 7 but Different Spot After Tempering 1 Hour at 570 Degrees Fahr. (300 Degrees Cent.). Chartkoff and Gladding.

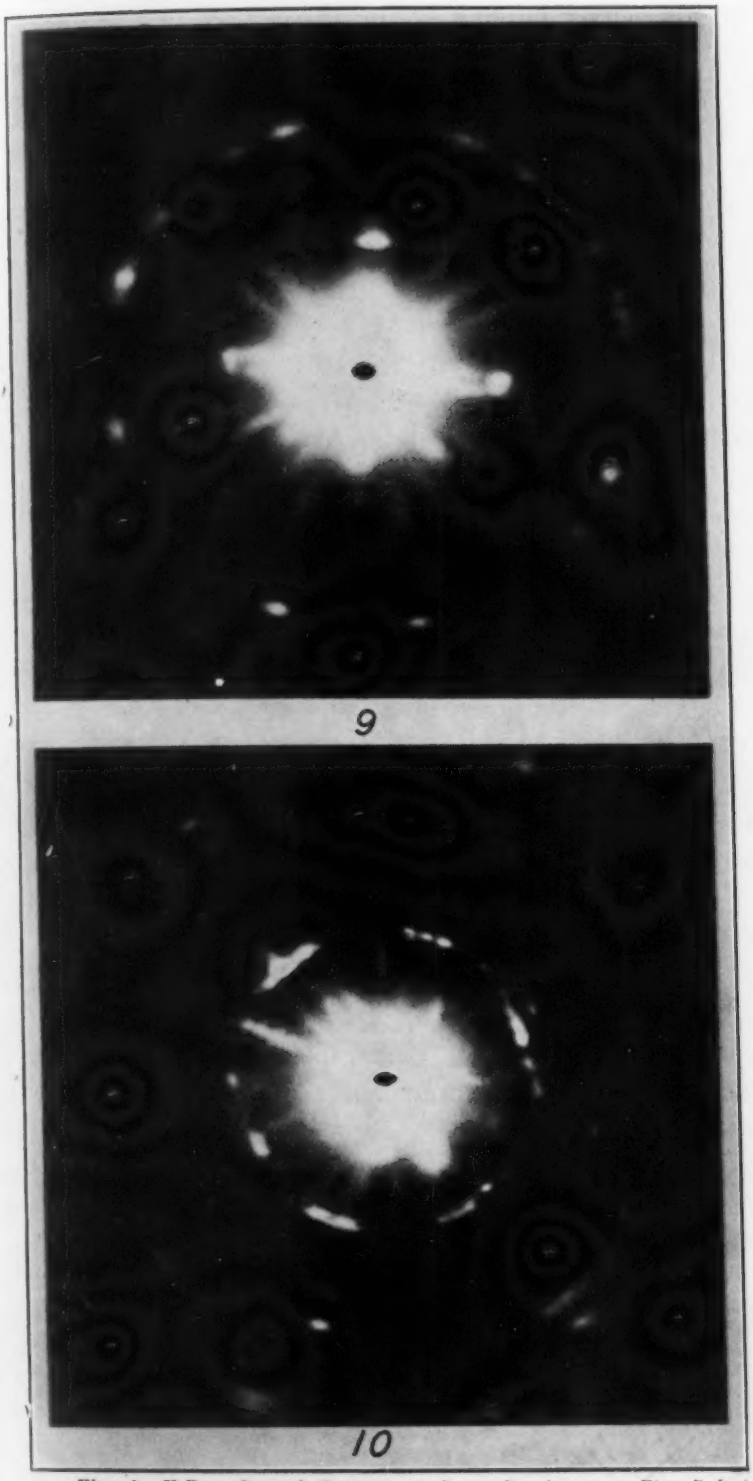


Fig. 9—X-Ray Crystal Pattern of Same Specimen as Fig. 7 but Different Spot After Tempering 1 Hour at 930 Degrees Fahr. (500 Degrees Cent.). Chartkoff and Gladding. Fig. 10—X-Ray Crystal Pattern of 1 Per Cent Carbon Steel Quenched from 2190 Degrees Fahr. (1200 Degrees Cent.). Chartkoff and Gladding.

suming that the tendency is for the nuclei to form with random orientations. It is possible, however, that the orientation directing force of the austenite crystal controls the orientation of the alpha iron nuclei. To answer this much more research is necessary.*

It is very significant that the transformation of austenite to pearlite and to carbide and alpha iron at 930 degrees Fahr. (500 degrees Cent.) produces a different result with respect to the orientation of the alpha iron than the transformation from austenite to martensite. This fact may be used as an argument that the two transformations are different in kind as postulated above.

Having now reached the conclusion that acicular martensite in carbon steel is alpha iron solid solution crystallized for the greater part in minute plates whose larger surfaces are parallel with one or more of the octahedral planes of the parent austenite and whose orientations bear some relation to the orientation of the parent austenite, we have yet to inquire as to the sizes of the alpha iron plates or grains. In some of the softer martensites as, for example, in the iron-nickel alloys and low carbon steels, the microscope gives us positive evidence on grain size. In the hard high carbon steel martensites the microscope fails us especially as to complete detail. Because of the tendency toward preferred orientation of the alpha iron grains of acicular martensite the X-ray does not give as satisfactory quantitative evidence on grain size as might be desired. Since hardness and grain size are so closely related they will be discussed together.

In the first place all acicular martensites are not hard. In fact some of them are quite soft. The iron-nickel alloy containing 19 per cent nickel, for example, when cooled rapidly from a temperature of 2280 degrees Fahr. (1250 degrees Cent.) to room temperature and then immersed in liquid oxygen has a martensitic structure but its Rockwell "C" hardness is only 18. The alpha iron solid solution is fairly coarse-grained for martensite. When heated to 1110 degrees Fahr. (600 degrees Cent.) to produce

*Since presenting this lecture Dr. L. W. McKeehan has called the writer's attention to a paper by J. Young, *Proceedings* of the Royal Society, 112-A, 1926, pages 630-641, showing that in meteoric iron the (1 1 0) planes of the alpha plates are parallel to the (1 1 1) planes of the gamma matrix. This means a preferred orientation of alpha grains with four fibering axes, the (1 1 1) lines in the gamma crystal. Dr. McKeehan suggests from the appearance of our X-ray patterns that the same relationship in orientation may exist in martensite as in meteoric iron. Our X-ray results are consistent with this view. Also in comparing the results of slip plane directions in the alpha grains of the 19 per cent nickel alloy with the directions of the octahedral planes of the parent gamma grains, this relationship seems to hold. It would thus appear that a general solution of this problem is "just around the corner" or perhaps already in sight.

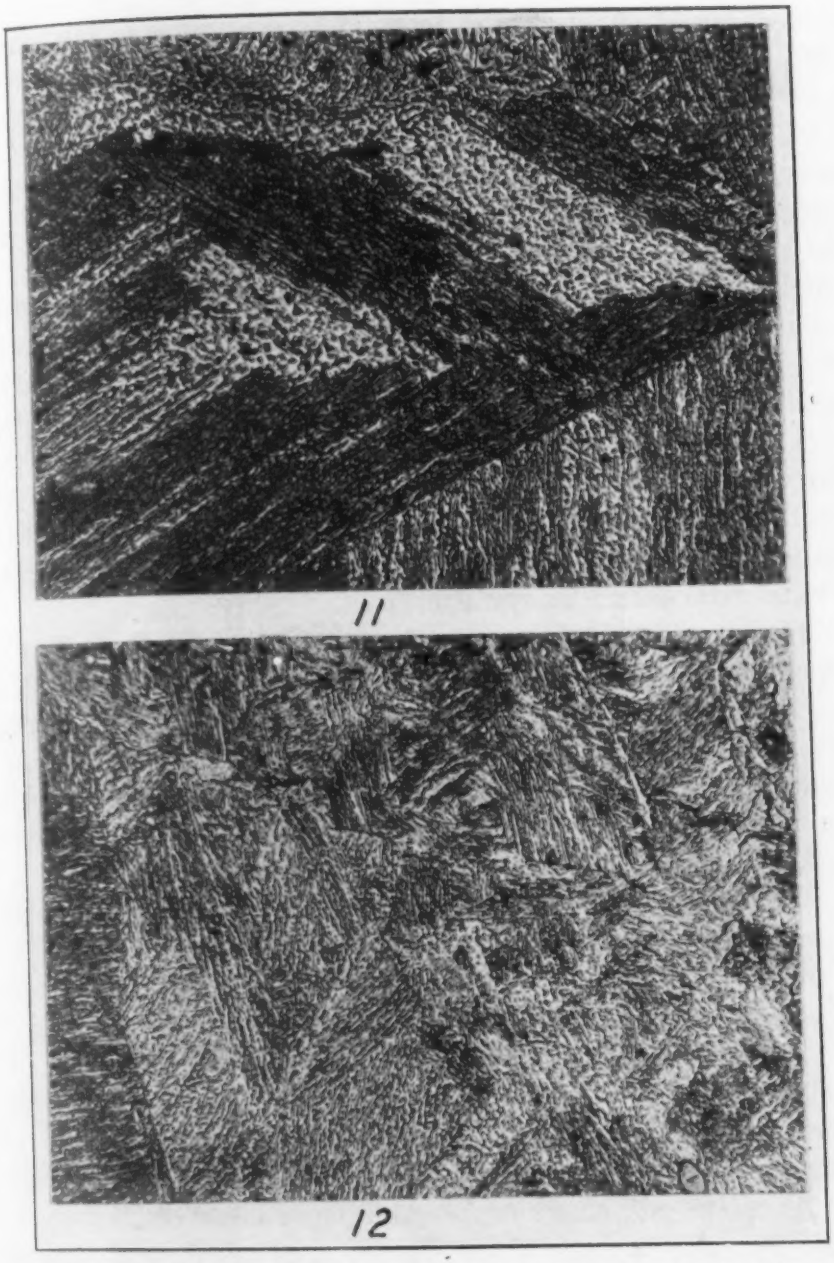


Fig. 11—Martensite Obtained by Quenching 0.1 Per Cent Carbon Steel from 2320 Degrees Fahr. 500 x. Roy H. Smith. Fig. 12—Martensite Obtained by Quenching 0.1 Per Cent Carbon Steel from 2105 Degrees Fahr. 500 x. Roy H. Smith.

fine-grained austenite and then quenched, the martensite is much finer grained and Rockwell hardness is increased to 22.5-C.

In this connection some 0.10 per cent carbon steel martensite prepared by Roy H. Smith is interesting. Figs. 11 and 12 show

the structures of two pieces quenched from 2320 to 2105 degrees Fahr. (1270 and 1150 degrees Cent.) magnified 500 diameters. The Rockwell "C" hardness of these steels is from 20 to 25, which is about the same as that of lamellar pearlite. Incidentally the refinement of structure is not greatly different from that of lamellar pearlite. These specimens show clearly that large areas may etch with a similar tint and yet be composed of many individual grains or platelets. It is very probable that areas having similar etching tints have many of the plates oriented similarly and that such similarity may defeat in a measure the hardening which would otherwise be associated with such grain refinement. Even in these 0.10 per cent carbon steel martensites some of the structure seems too fine for resolution at 500 diameters. With a structure much finer the detail might be unresolvable with the microscope and an area etching with a similar tint might be wrongly referred to as one grain.

The structure of martensite in general becomes finer the higher the carbon content at least up to about 0.60 per cent, and the smaller the parent austenite grains. Eutectoid steel quenched from just above the critical temperature is often referred to as "structureless" martensite or hardenite. The parent austenite grain size is small and the carbon content relatively high and the detail of the structure is too fine for microscopic resolution.

The hardness of hard martensite has been attributed to many causes. Two of these causes are the internal strains resulting from the increase in volume during the formation of martensite and the plastic deformation resulting from this volume increase. In view of the fact that an iron-nickel alloy containing 19 per cent nickel undergoes its transformation at about the same temperature as the transformation of high carbon steel from austenite to martensite, and is accompanied by about the same expansion and is soft, these two supposed causes can be eliminated as important factors in producing slip interference. The presence of hard cementite in minute particles seems necessary in order to produce maximum attainable hardness but these particles appear to be absent in freshly formed martensite which may be quite hard. The factors contributing to the hardness of freshly formed martensite are thus reduced to two, namely, the hardening of pure alpha iron crystals due to other elements in solid solution and the hardening resulting from grain refinement. The problem

now appears to be one of appraising the contribution of solid solution and of grain refinement hardening. That both are hardening factors is generally admitted. That the two factors should co-operate to produce high hardness also seems logical.

One of the outstanding developments in the science of metals

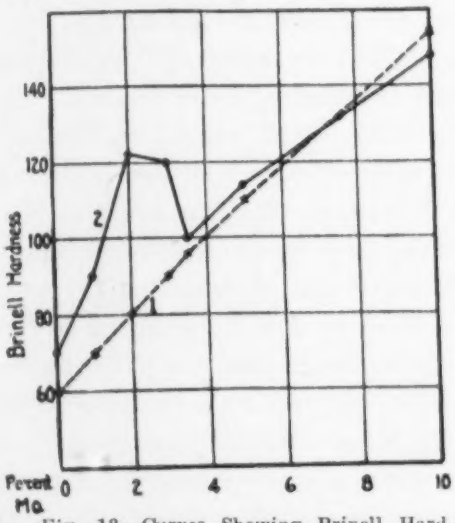


Fig. 13—Curves Showing Brinell Hardness of Iron-Molybdenum Alloys. (1) Cooled from 2685 Degrees Fahr. (1475 Degrees Cent.) to 930 Degrees Fahr. (500 Degrees Cent.) in 1 Hour. (2) Water Quenched from 2685 Degrees Fahr. (1475 Degrees Cent.). Sykes.

in recent years is the production of hard carbon-free alloys of iron and molybdenum by Sykes.[17]

In Fig. 13 the dotted line shows how coarse-grained alpha iron is hardened by molybdenum in solid solution. The solid line shows added hardening of pure alpha iron and of the dilute solutions of molybdenum in alpha iron due to moderate grain refinement. Beyond 4 per cent molybdenum it is not possible to refine the grain of these alloys by heat treatment because the solutions are body-centered cubic at all temperatures up to melting. The saturated solid solution at 2600 degrees Fahr. (1425 degrees Cent.) contains about 22 per cent molybdenum which can be preserved at room temperature by quenching. Its Brinell hardness is about 215. After aging for a few days at 1020 degrees Fahr. (550 degrees Cent.) the Brinell hardness is above 500, which is in the range of hard steel. Here the major hardening effect can definitely be assigned to a fine precipitate of iron molyb-

[17] TRANSACTIONS, American Society for Steel Treating, Vol. 10; 1926, p. 839.

dide, $Fe_3Mo_2$, in a soft solid solution of about 6 per cent molybdenum in alpha iron. The solid solution itself has a Brinell hardness of only about 120. The particles of $Fe_3Mo_2$ are too small to be resolved with the microscope but their presence is suggested by the etching effect.

If alpha iron containing a few tenths of a per cent of carbon in solid solution is very hard the grains need not be very fine to account for the hardness of martensite. If the solid solution is not very hard then grain refinement must be resorted to to account for a considerable part of the hardness. Unfortunately for purposes of determining the causes of hardness, but fortunately for industrial purposes, the solid solutions of carbon in alpha iron containing more than about 0.10 per cent carbon are always relatively fine-grained. Such solid solutions are not in equilibrium at any temperature and the only way they can be produced is by defeating the establishment of equilibrium under conditions which prohibit the free formation of large grains. Any attempt to coarsen these grains by heating results in decomposition.

W. P. Sykes and the author have endeavored to separate the hardening due to carbon in solution and that due to grain refinement in an alloy of iron containing 19 per cent nickel, kindly supplied by Professor Honda. In the carbon-free alloy cooled from a high temperature the structure was martensitic and the Rockwell "C" hardness 18. This hardness is partly due to the nickel in solid solution in alpha iron and partly to grain refinement. The structure is shown in Fig. 14, magnified 200 diameters. By cooling the same sample from 1110 degrees Fahr. (600 degrees Cent.) the structure was a finer grained martensite and the Rockwell "C" hardness was increased from 18 to 22.5. This added hardness can be attributed entirely to further grain refinement. A piece of the iron-nickel alloy was carburized by a mixture of hydrogen and natural gas until it contained 0.012 per cent carbon. When quenched from 2280 degrees Fahr. (1250 degrees Cent.) the Rockwell "C" hardness was 26 and the structure was that shown in Fig. 15, magnified 200 diameters. Examination at higher magnification reveals considerable fine detailed structure. When this specimen was reheated and quenched from 1110 degrees Fahr. (600 degrees Cent.) its Rockwell "C" hardness was 31 and the martensitic structure was considerably finer grained as shown in Fig. 16, magnified 200 diameters.

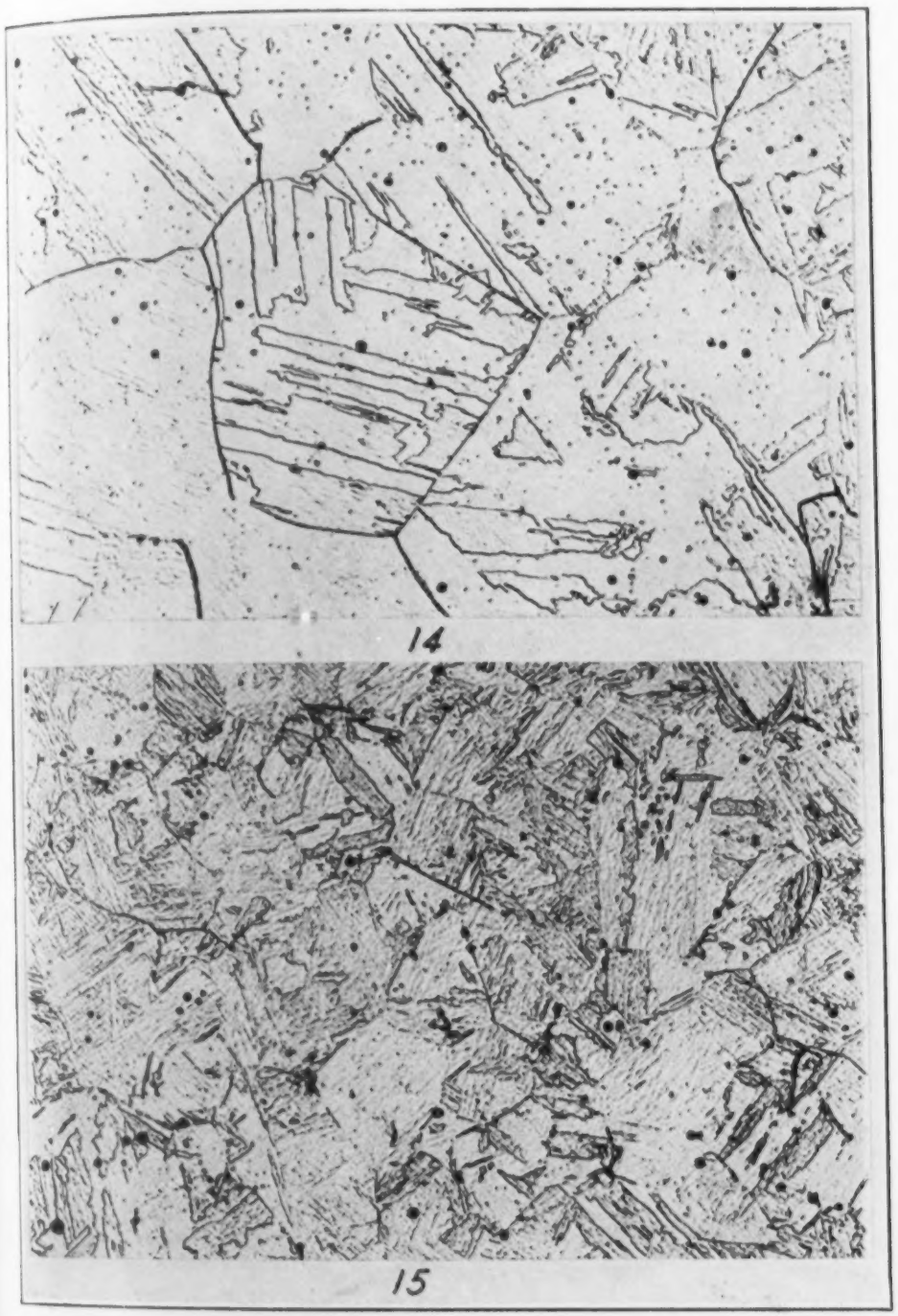


Fig. 14—Alloy Containing 81 Per Cent Iron and 19 Per Cent Nickel Quenched from 2280 Degrees Fahr. (1250 Degrees Cent.). Rockwell Hardness 18 C. 200 x. L. W. Kempf.
Fig. 15—Same Alloy as Fig. 14. Carburized to Contain 0.012 Per Cent Carbon Quenched from 2280 Degrees Fahr. (1250 Degrees Cent.). Rockwell Hardness 28 C. 200 x. L. W. Kempf.

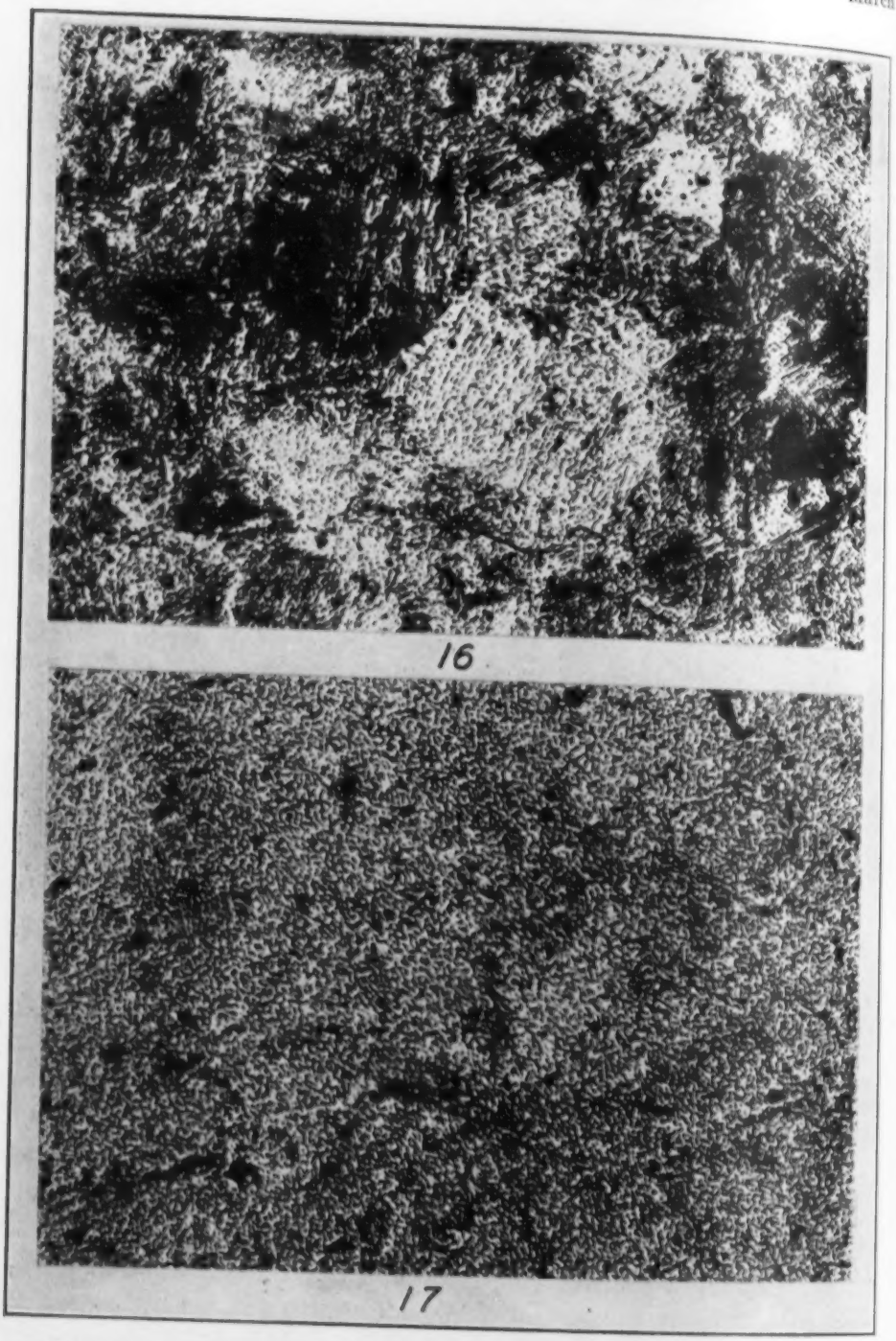


Fig. 16—Same Specimen as Fig. 15, Reheated to 1110 Degrees Fahr. (600 Degrees Cent.) and Quenched. Rockwell Hardness 31 C. 200 x. L. W. Kempf. Fig. 17—Same Alloy as Fig. 14, Carburized to Contain About 0.05 Per Cent Carbon, Quenched from 1110 Degrees Fahr. (600 Degrees Cent.). Rockwell Hardness 45 C. 200 x. L. W. Kempf.

By increasing the carbon content to about 0.05 per cent the Rockwell "C" hardness after quenching from 2280 degrees Fahr. (1250 degrees Cent.) was 36.5 and after quenching from 1110 degrees Fahr. (600 degrees Cent.) the hardness was 45. The structure of the specimen quenched from 1110 degrees Fahr. (600 degrees Cent.) is shown in Fig. 17, magnified 200 diameters. The hardness increase of the 0.012 per cent carbon sample from 26 to 31 and of the 0.05 per cent carbon sample from 36.5 to 45 can be attributed entirely to further grain refinement. No way was found to determine the amount of hardening in the softer samples due to the alpha iron solid solution and to grain refinement.

An important observation was made, however, on the effect of the carbon on the structure. Whereas in the carbon-free alloys it was not difficult to form alpha solid solution grains easily visible with the microscope under low power and it seemed impossible to refine the structure beyond the resolving power of the microscope, with 0.05 per cent carbon it was more difficult to produce alpha iron solid solution grains in the larger sizes and by quenching from 1110 degrees Fahr. (600 degrees Cent.) the structure was so fine as to be, at least for the greater part, unresolvable under the microscope. The carbon therefore seems to act definitely and effectively as a grain refiner of the martensite. Another point of interest and significance is that the structure is uniform from center to surface of the specimen. This specimen might be referred to as a deep hardening steel.

It thus appears that carbon plays at least three rôles in the hardening and hardness of unaged carbon steel. Carbon assists in lowering the temperature of the allotropic transformation, it assists in producing smaller alpha iron solid solution grains when martensite forms and finally it hardens by its presence in solid solution. If another element is present like nickel to lower the temperature of the allotropic transformation then a small amount of carbon becomes effective as a grain refiner.

It is certain that high carbon steel martensite can have the appearance of having some structural elements easily resolvable under the microscope and still be very hard. Lucas[18] has come to the conclusion that these needles are not single crystals. Fig. 18, magnified 3750 diameters, shows the detail on which he bases this conclusion in part. Carbide would be precipitated in the mar-

[18] TRANSACTIONS, American Society for Steel Treating, Vol. 6, 1924, p. 669

Fig 18—High Carbon Steel Quenched from High Temperature. 3750 x. F. F. Lucas.

tensite at room temperature so the conclusion of Lucas is undoubtedly correct. A question which needs answering is whether or not the alpha iron in one martensite needle is one grain. If not, grain refinement would account for the hardening even though the solid solution were relatively soft; if so, then more hardness is required in the solid solution.

Even if these needles of martensite represent the true grains of alpha iron solid solution much of the structure in any hard martensite is beyond definite microscopic resolution. The filling-in material between and around the larger needles is often very fine grained. This filling material has the commanding position of continuity so its hardness would protect the larger needles if they are soft. Thus considerable microscopically visible austenite, known to be soft by itself, can be surrounded by hard martensite without making the steel soft. So it should be possible for the larger needles to be relatively soft without making the steel soft. The completion of the transformation seems to become more difficult as the carbon content increases so that crystallization parallel to all of the octahedral planes takes place. This produces a very fine-grained structure surrounding the larger needles or plates. Just as the size of the austenite grains determine the maximum length of the first martensite needles to form so these needles act as boundaries limiting the length of additional needles on intersecting planes and so on until the platelets or needles in the last austenite to transform must be very short. This principle is illustrated in Fig. 19, magnified 2400 diameters, one of Lucas' photomicrographs of high carbon martensite and austenite. The fineness of the structure between the main needles is apparent. The needles might be only moderately harder than austenite and yet the structure as a whole would be hard.

While it seems impossible to assign any definite values as to the proportion of the hardening due to solid solution on the one hand and grain refinement on the other, it might be mentioned that if alpha iron containing say 0.50 per cent carbon in solution is hard enough to account for the hardness of a 0.50 per cent carbon quenched steel, it is the only case known of such a hardening effect due to solid solution not only in iron but in any other metal. It must be taken into consideration, however, that no other metallic solid solution can be obtained with the degree of super-

Fig. 19—High Carbon Steel Quenched from High Temperature. 2400 x. F. F. Lucas.

saturation of the solid solution of carbon in alpha iron. On the other hand there seems to be no way of obtaining the degree of grain refinement in other alloys that can be obtained by quenching a carbon-containing steel. Wykoff has produced iron powder by reducing a fine powder of iron oxide and by subjecting this fine iron powder to high compression, briquets were obtained having a hardness comparable with that of hard steel. This shows that great grain refinement of a soft material is capable of producing high hardness. The fact that martensite containing coarse needles or plates is softer than martensite of the same

composition not containing coarse needles or plates strongly suggests, (1), that each needle or plate may be a single alpha iron solid solution grain, and, (2), that the decrease in hardness is the result of the presence of these relatively coarse grains.

Some metallurgists do not admit that the hardness of martensite can be accounted for by grain refinement and solid solution. Others believe with LeChatelier that the hardness can be accounted for by solid solution alone. For example, Scott[19] in discussing a paper by Bain, "The Nature of Martensite," makes the following statement: ". . . the hardness of martensite is directly associated with the amount of dissolved carbon. The author states that carbon distorts the space lattice of iron and has a strong chemical affinity for iron. Are not these facts sufficient to explain the great hardness of martensite without recourse to the involved grain size theory?" Scott draws these conclusions largely from the fact that the hardness of martensite increases as the carbon content increases. It is certainly to be expected that the solution of carbon in alpha iron of given grain size will be harder the higher the carbon content. Many researches have indicated that the hardness of carbon steel martensite increases linearly as the carbon content increases up to about 0.70 per cent. This relationship has been used as an argument favoring solid solution as the major cause of hardening. If the grain refinement also increases as the carbon content increases, at least with certain rates of cooling, the approximate linear relationship would also obtain and the slope of the line would be steep, that is, the increase in hardness would be great for a given addition of carbon.

In discussing the same paper, Rawdon described experiments showing how electrolytic iron containing 0.02 per cent carbon can be made "very hard" by melting a minute portion of a specimen with an electric arc. The molten globule solidifies and cools to room temperature very rapidly. ". . . . the finger tip can be placed upon the spot immediately after the spark has passed without any feeling of discomfort." Specimens arced in vacuum and in argon were hard, showing that the hardening of the air-arced samples was not due to nitrogen absorption. "Steel of 0.07 per cent carbon, when fused by sparking and cooled immediately, has a hard, glasslike surface over which the jewel point of the scratch

[19] *Transactions*, American Institute of Mining and Metallurgical Engineers, Vol. 70, 1924, p. 42.

hardness instrument glides without making any appreciable cut." Rawdon concludes that carbon does not seem to be fundamentally essential in the hardening process, although it is a powerful adjunct. The experimental results on which Scott based his conclusion that hardening is due to carbon in solid solution can be interpreted equally well by assuming that grain refinement is the

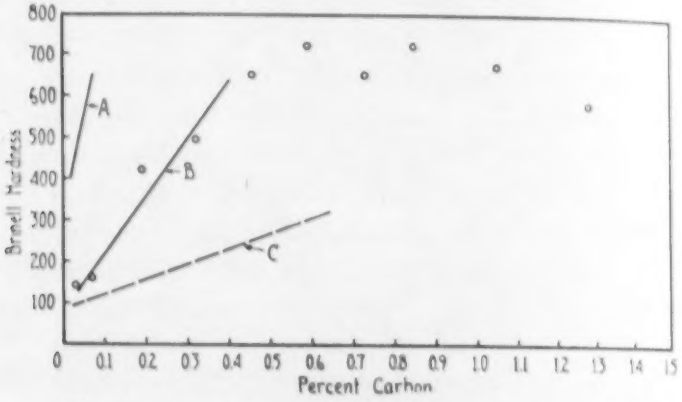


Fig. 20—A. Approximate Carbon-Content-Hardness Relationship of Rawdon's Extraordinary Quenching. B. Actual Carbon-Content-Hardness Relationship Obtained by Scott. C. Suggested Carbon-Content-Hardness Relationship Due to Solid Solution of Carbon in Alpha Iron.

principal cause of the hardness. To explain the experimental results obtained by Rawdon, however, the hardening due to carbon in solid solution must be assigned a very secondary rôle.

When Archer[20] and the author concluded that grain refinement in martensite was a more important hardening factor than solid solution we did not have access to the experimental results of Wykoff or Rawdon. Archer had made the observation that the hardness of greatly supersaturated coarse-grained solid solutions of copper in aluminum bore a linear relationship with respect to dilute unsaturated solutions. Such evidence as we could obtain on quenched specimens indicated that the first additions of carbon to iron did not produce nearly as much increase in hardness as would be required to account for the hardness of say a quenched 0.20 per cent carbon steel on the basis of a linear relationship. Assuming that supersaturated solid solutions of carbon in alpha iron of a given grain size should obey the linear relationship, a relationship which Sykes has now shown to hold for supersaturated solid solutions of molybdenum in alpha iron, some other hardening factor must be present to account for the hardness of hard

[20] *Chemical and Metallurgical Engineering*, 1921, Vol. 24, p. 1057.

freshly formed martensite. The hardening effect of small amounts of carbon in solid solution in coarse-grained alpha iron should be determined carefully to ascertain the degree of departure from this linear relationship. Pure iron could be heated to about 1290 to 1380 degrees Fahr. (700 to 750 degrees Cent.) in atmospheres of hydrogen containing such amounts of methane or other hydrocarbon as to slightly carburize the alpha iron, followed by quenching.

In Fig. 20 I have indicated the approximate relations between hardness and carbon content in Rawdon's extraordinary quenching experiments, Scott's ordinary quenching experiments and suggested hardness values of coarse-grained solid solutions of carbon in alpha iron. The values assigned in Rawdon's experiments are based on the fact that the scratch hardness of arced electrolytic iron was about the same as a heat treated steel with a Brinell hardness of 400 and the arced 0.07 per cent carbon steel was considerably harder.

## Age Hardened Martensite

It is well known that diffusion is more rapid at grain boundaries than through the crystals themselves. Room temperature is near the temperature limit which will permit diffusion of carbon in steel. It is very probable that most of the age hardening in freshly quenched martensite during the first few hours at room temperature and during the first few minutes at 100 degrees Cent. is due to precipitation of the carbide in grain boundaries. The relatively rapid rate of hardening at the beginning of aging is consistent with this view and with the presence of much grain boundary, that is, great grain refinement. In fact it is conceivable that age hardening in some of the larger grains of alpha iron solid solution would lag considerably behind the finer grained portions. Probably higher temperatures would be required for carbide precipitation in low carbon than in high carbon steels.

In the hardest steels produced recently by Sykes and the author it would appear that the hardening is due largely to grain refinement and the presence of iron carbide in very small particles. The reason for definitely assigning a minor place to solid solution in these steels is that they are apparently aged until most of the carbon is precipitated. This conclusion is based on maximum hardness being due to a critical size of precipitated particle. These hard steels are quenched and then immersed in liquid oxy-

gen and then aged 150 hours at 50 degrees Cent. If aged 200 hours at 50 degrees Cent. the hardness decreases somewhat, indicating growth of the carbide particles above critical size for maximum hardness. Such growth would seem to demand a solid solution supersaturated with respect to the larger particles of carbide and undersaturated with respect to the smaller particles. If the alpha iron solid solution is undersaturated in carbon with respect to the smaller carbide particles it should not contain much carbon and hence should not be hard if coarse-grained. Just how much carbon this is is another problem which needs quantitative investigation. Andrew[21] and his coworkers conclude from electrical resistivity measurements that about a quarter of a per cent of carbon remains in solution in the alpha iron after mild tempering.

The volume changes and electrical properties, such as resistance and magnetism, if interpreted according to the classical rules of coarser grained aggregates, would indicate that precipitation of the carbide is not nearly complete in a quenched high carbon steel aged 150 hours at 50 degrees Cent. Professor Campbell ingeniously provided for these apparent anomalies by assuming that the carbide could exist in molecules containing different numbers of atoms. He assumed that the larger molecules of iron carbide, containing many $Fe_3C$ units could still be in solid solution and would impart solid solution characteristics to the steel. Our present conception is very little different from Professor Campbell's. Because we believe that precipitation of the carbide represents the appearance of a new crystalline phase we prefer to call the structure an aggregate in which the newly precipitated phase is very finely dispersed. Because we have now observed some of the same anomalies in nonferrous alloys it has been concluded that certain of the properties of fine dispersoids resemble the properties of solid solutions. A deeper study of the properties of fine dispersoids is needed in order to reconcile their properties with those of coarser grained aggregates and with solid solutions.

In concluding this discussion of one of the most baffling subjects in the science of metals may I express the hope that this hour, set aside in commemoration of the work of Edward DeMille Campbell, may stimulate more and better work on the subject so dear to his heart,—the constitution and hardening of steel.

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[21] *Proceedings*, Royal Society, Series A, Vol. 110, No. A-754, p. 391.

# FATIGUE TESTS OF CARBURIZED STEEL

By H. F. Moore and N. J. Alleman

*Abstract*

*This paper presents the results of fatigue tests and of static tension tests of carburized steel. Three steels were studied; a plain carbon steel, a nickel steel, and a chromium-nickel steel. Several different treatments were tried for each steel. In general, the test results suggest that carburizing, followed by suitable heat treatment, is a promising means of increasing the fatigue strength of steel as well as an effective means of increasing surface hardness. Steel quenched in oil from the carburizing pot showed more increase in fatigue strength than did steel cooled in the carburizing pot.*

## Introductory

CARBURIZING of steel, followed by case hardening, is frequently used as the means of securing a hard wearing surface on a steel part. It also may be used to strengthen the skin of the part by increasing the carbon content, and this strengthening effect is especially marked if after carburizing, a suitable heat treatment is used. Test data on this strengthening effect are few[1], and the tests herein described have been carried out with the purpose of adding to the knowledge of the strength of carburized steel.

*Materials and Test Specimens:* Three steels were studied: (1) a plain carbon steel, S. A. E. 1020 given a laboratory number 23, (2) a nickel steel, S. A. E. 2320 laboratory number 24, and (3) a chromium-nickel steel, S. A. E. 3120, laboratory number 25. The approximate chemical composition of these steels is given in Table I. The steels were purchased in the open market in the form of round bars ¾ inch in diameter.

The static tension test specimen is shown in Fig. 1. A rotating-beam specimen for fatigue tests is shown in Fig. 2. The reduced portion of the fatigue specimen is turned down with a

[1]See tests by Muller, Bulletin 152, Eng. Expt. Sta., Univ. of Ill., p. 63, also tests by Woodvine, Carnegie Scholarship Memoirs of the (British) Iron and Steel Institute, 1924, p. 197.

A paper presented before the ninth annual convention of the society held in Detroit, September 19 to 23, 1927. Of the authors, who are members of the society, H. F. Moore is research professor of engineering materials in charge of the investigation of the fatigue of metals, and N. J. Alleman is assistant engineer of tests, investigation of the fatigue of metals, University of Illinois, Urbana, Illinois. Manuscript received July 13, 1927.

tool swung on a 5-inch radius. There is no sudden change of contour in this specimen, and hence no highly localized stresses. The specimens for hardness tests (Brinell, Rockwell, scleroscope, and Herbert pendulum) consisted of cylinders of metal ½ inch in diameter by ½ inch long. All specimens were machined to

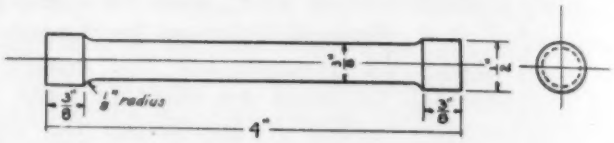


Fig. 1—Sketch of Tension Test Bar Used in This Investigation.

shape before carburizing, and after machining, the surface of each specimen was smooth-turned and polished with 000 emery cloth before being carburized.

*Carburizing and Heat Treatment:* The carburizing process for each steel was carried out with the idea of securing a case about 1/32 inch thick. This thickness seems to be a good average value both for the fatigue specimens, which were 0.300 inch minimum diameter, and for the tension specimens, which were 0.375 inch minimum diameter. After being carburized the specimens were not ground, so that the thickness of the case was not dim-

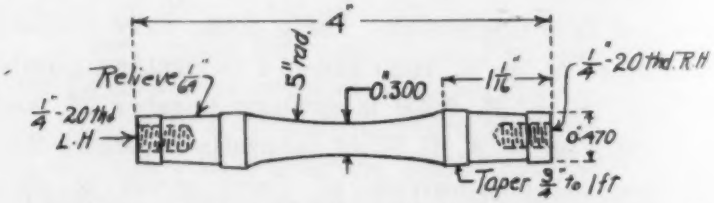


Fig. 2—Rotating Beam Fatigue Test Specimen Used in Making Tests Described in This Investigation.

inished. The thickness of case was determined by grinding and etching the end of a specimen, and then examining it under a low-power microscope.

A good commercial carburizing compound was used. A mixture of equal parts of old compound and of fresh compound was used for all specimens except for the carbon steel specimens for heat treatments B, C, and D, which were carburized with fresh compound. The temperatures used in carburizing and in the subsequent heat treatments are given in Table II, and the different heat treatments used (designated by letters) are given in Table III.

**Table I**
**Approximate Chemical Composition of Steels Tested**

| Steel | Laboratory Number | Content, per cent | | | | | |
|---|---|---|---|---|---|---|---|
| | | Carbon | Manganese | Phosphorus | Sulphur | Nickel | Chromium |
| Carbon Steel S. A. E. 1020 | 23 | 0.20 | 0.45 | not over 0.045 | not over 0.05 | ... | ... |
| Nickel steel S. A. E. 2320 | 24 | 0.20 | 0.65 | not over 0.04 | not over 0.045 | 3.50 | ... |
| Chromium-nickel steel S. A. E. 3120 | 25 | 0.20 | 0.65 | not over 0.04 | not over 0.045 | 1.25 | 0.60 |

The carbon steels, treatments B, C, and D, were carburized for two hours, and the resulting thickness of case was found to be 0.078 inch. The carbon steels, treatments E, F, and G were carburized for 1 hour after which the containers were withdrawn and cooled in air. The resulting thickness of case was found to be 0.020 inch. The nickel steels, treatments B, C, and D were carburized for 2¼ hours with a resulting thickness of case of 0.025 inch. The chromium-nickel steels, treatments B, C, and D were held at carburizing heat for 3 hours, giving a thickness of case of 0.032 inch.

**Table II**
**Temperatures Used for Carburizing and for Subsequent Heat Treatment**
Temperatures are those given in S. A. E. specifications.
All temperatures are in degrees Fahrenheit.

| Treatment | Carbon Steel S. A. E. 1020 (Lab. No. 23) | Nickel Steel S. A. E. 2320 (Lab. No. 24) | Chromium-Nickel Steel S. A. E. 3120 (Lab. No. 25) |
|---|---|---|---|
| Carburizing ..... | 1650-1700 | 1600-1650 | 1625-1675 |
| Core refining ..... | 1650 | 1625 | 1650 |
| Case refining ..... | 1450 | 1400 | 1400 |

In treatments B, C, and D for all steels the specimens were held at the designated temperature for the time given in the preceding paragraph, and then oil-quenched from the carburizing pot.

**Table III**
**Heat Treatments Used in Tests of Case-Carburized Steel**

| Heat Treatment | Details of Heat Treatment |
|---|---|
| A | Steel tested as received (hot-rolled) |
| B | Steel carburized and oil-quenched from pot |
| C | Steel carburized, oil-quenched from pot, and then heated to refining temperature for the case (See Table II) |
| D | Steel carburized, oil-quenched from pot, heated to refining temperature for core, and then heated to refining temperature for case (See Table II) |
| E | Steel carburized and cooled in pot |
| F | Steel carburized, cooled in pot, and then heated to refining temperature for the case (See Table II) |
| G | Steel carburized, cooled in pot, heated to refining temperature for core, and then heated to refining temperature for case (See Table II) |

In all refining treatments the temperature was held for 30 minutes, after which the specimens were oil-quenched. After this quench the specimens were not further tempered.

Specimens of carbon steel for treatments B, C, and D were carburized in a cast iron box 4 by 8 by 12 inches, and the carburizing was done in a gas-fired furnace. The temperature was measured by means of a thermocouple in contact with the top surface of the box. All other specimens were carburized in containers made of sections of 4-inch pipe 12 inches long. These containers were capped and plugged with fireclay. Provision was made for the insertion of a thermocouple in one end of a container. The carburizing and refining were carried out in an electric furnace. Each container held a set of specimens consisting of 8 fatigue specimens, 3 tension specimens, and 3 hardness test specimens.

*Testing Machines, Tests, and Test Data.* For the static tension tests a 3-screw 100,000-lb. testing machine was used. Robertson shackles[2] were used to insure axial loading. Measurements of deformation were made with an extensometer with a gage-length of 2 inches, and reading to one ten-thousandth of an inch stretch. The speed of the head of the testing machine for all specimens within the yield point was 0.05 inch per minute, for the more brit-

[2]For a description of the Robertson shackle see the 1921 report of the British Aeronautical Research Committee, also Bull. 164, Eng. Expt. Sta., Univ. of Ill., p. 13.

tle specimens this speed was continued to fracture; for the more ductile specimens the speed beyond the yield point was 0.3 inch per minute.

Fatigue tests were run in a "Sondericker" or "Farmer" rotating beam machine fitted with holders for short specimens. This machine is shown in Fig. 3. Especial care was taken to see that the rotating-beam specimens ran smoothly. Vibration seemed to

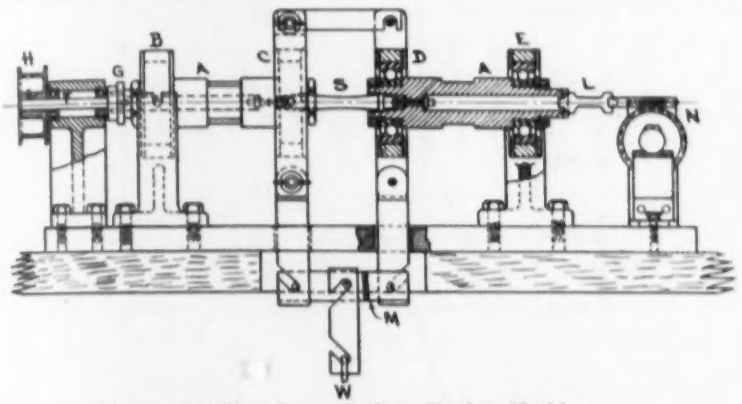


Fig. 3—Rotating Beam Fatigue Testing Machine:

(a) Specimen Holders
(b) Ball Bearings
(f) Driving Shaft
(g) Leather Coupling
(h) Driving Pulley
(l) Counter Drive Link
(m) Equalizing Bar
(n) Revolution Counter
(s) Fatigue Test Specimen
(w) Load

produce an appreciable effect on fatigue strength, especially in the case of specimens of steel quenched directly from the carburizing pot, with no further heat treatment. The metal so treated was decidedly brittle.

Brinell tests were made on an Alpha machine using a 10-millimeter ball and loads of 3000, 2000, and 1000 kilograms. Scleroscope tests were made with a model D scleroscope and Rockwell "C" tests were made with the standard diamond cone and a 150-kilogram load; Rockwell "B" tests were made with 1/16 inch steel ball and a 100-kilogram load. Herbert pendulum tests were made using a 4-kilogram pendulum and a 1-millimeter steel ball.

Figs. 4, 5, 6, and 7 show characteristic stress-strain diagrams for tension tests. It will be noted that for the specimens given a refining treatment there are two fairly well marked "breaks" in the stress-strain diagram. Presumably the lower "break" marks the beginning of yielding in the core, and the higher "break" the beginning of yielding in the case. The results of the static ten-

sion tests, and of the various hardness tests are given in Table IV.

As is customary the fatigue test data is plotted in diagrams in which the ordinates are values of computed stress (computed

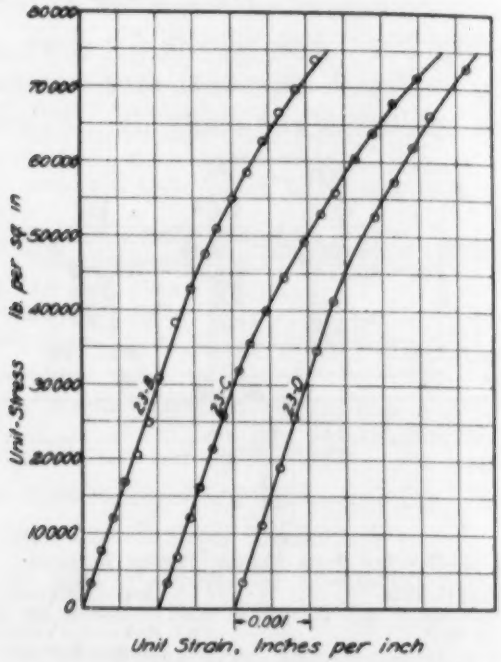


Fig. 4—Stress-Strain Diagrams for Quenched Specimens of Plain Carbon Steel S. A. E. 1020.

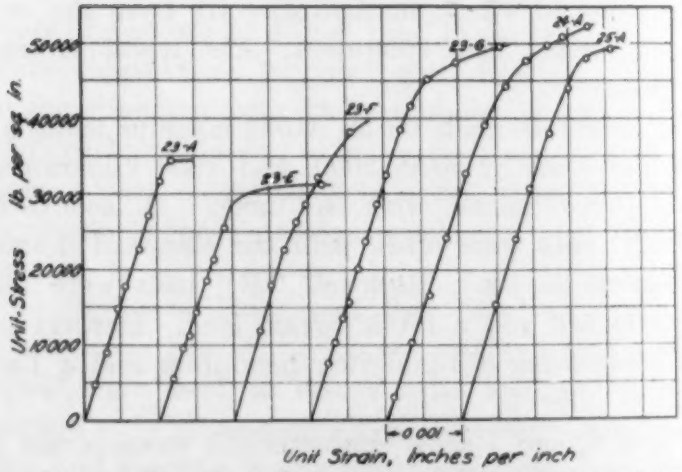


Fig. 5—Stress-Strain Diagrams for Steels as Received and for Cooled-in-the-Pot Specimen of Plain Carbon Steel.

by the common flexure formula) and the abscissas are numbers of cycles of stress for fracture. These diagrams are called S-N diagrams and in this paper are plotted to logarithmic coordinates.

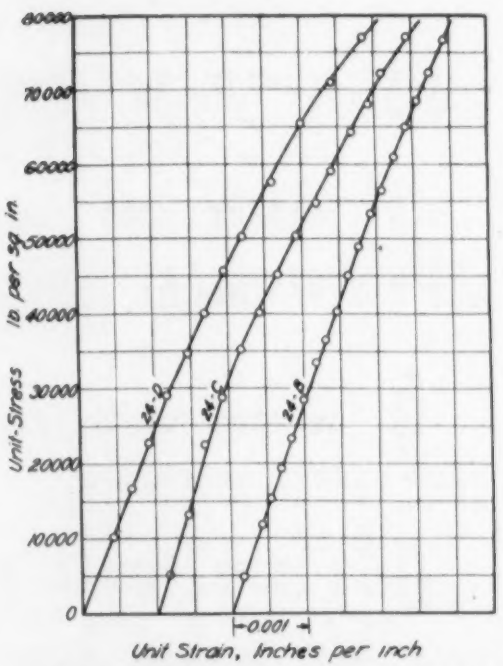


Fig. 6—Stress-Strain Diagrams of Quenched Specimens of Nickel-Steel S. A. E. 2320.

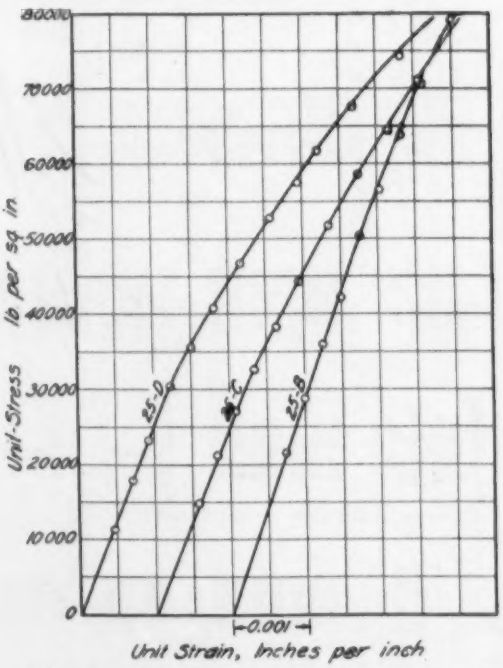


Fig. 7—Stress-Strain Diagrams of Quenched Specimens of Chromium-Nickel Steel S. A. E. 3120.

Figs. 8-12 inclusive give the S-N diagrams for the specimens tested. These S-N diagrams, like the characteristic S-N diagrams

## Table IV
## Results of Tension Tests and of Hardness Tests

| Treatment | Depth of Case, In. | Proportional Elastic Limit,* Lbs. Per Sq. In. | Tensile Strength, Lbs. Per Sq. In. | Elongation in 2 In., Per Cent | Reduction of Area, Per Cent | Brinell Number | Scleroscope Number | Rockwell Number "B" | Rockwell Number "C" | Herbert Pendulum Number |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | RESULTS OF TENSION TESTS | | | RESULTS OF HARDNESS TESTS | | | | |
| | | | CARBON STEEL, S. A. E. 1020 (Lab. No. 23) | | | | | | | |
| A | none | 34,400 | 60,200 | 38.8 | 66 | 104 | 19 | 64 | 17 | 23 |
| B | 0.030 | 37,800 | 88,800 | † | † | ... | 56 | 120 | 60 | 76 |
| C | 0.030 | 35,700 | 120,200 | 8.0 | 18 | 215 | 54 | 109 | 38 | 37 |
| D | 0.030 | 41,700 | 130,300 | 10.5 | 22 | 244 | 53 | 111 | 38 | 38 |
| E | 0.020 | 27,000 | 66,300 | 13.0 | 25 | 111 | 23 | 83 | 10 | 32 |
| F | 0.026 | 24,000 | 87,900 | 13.0 | 31 | 192 | 31 | 105 | 22 | 42 |
| G | 0.020 | 41,200 | 90,400 | 16.8 | 34 | 187 | 41 | 107 | 36 | 64 |
| | | | NICKEL STEEL, S. A. E. 2320 (Lab. No. 24) | | | | | | | |
| A | none | 38,300 | 96,000 | 20.2 | 58 | 204 | 30 | 89 | 13 | 30 |
| B | 0.025 | ‡ | 187,500 | † | † | 417 | 82 | .. | 64 | 76 |
| C | 0.025 | ‡ | 118,500 | † | † | 383 | 81 | .. | 63 | 77 |
| D | 0.025 | ‡ | 107,000 | † | † | 402 | 82 | .. | 64 | 77 |
| | | | CHROMIUM-NICKEL STEEL, S. A. E. 3120 (Lab. No. 25) | | | | | | | |
| A | none | 42,500 | 77,400 | 27.5 | 72 | 144 | 22 | 83 | 3 | 26 |
| B | 0.032 | ‡ | 141,500 | † | † | ... | 73 | 94 | 65 | 66 |
| C | 0.032 | ‡ | 102,000 | † | † | ... | 89 | .. | 67 | 73 |
| D | 0.032 | ‡ | 94,700 | † | † | 342 | 89 | .. | 67 | 75 |

*Proportional elastic limit determined by modification of method II of A. S. T. M. tentative standard method (J. B. Johnson method). Limit was located at stress, for which rate of elongation was 25 per cent greater than its value at low loads. For details of method see Bulletin 124, Eng. Expt. Sta., Univ. of Illinois, p. 50.

†Elongation and reduction of area very slight.

‡Proportional elastic limit very poorly defined.

Table V

Results of Fatigue Tests of Carburized Steel

| Steel | Heat Treatment | Depth of Case, In. | Endurance Limit (Rotating Beam), Lbs. Per Sq. In. | Tensile Strength, Lbs. Per Sq. In. | Endurance Ratio* | Increase of Tensile Strength Due to Carburizing, Per Cent | Increase of Endurance Limit Due to Carburizing, Per Cent |
|---|---|---|---|---|---|---|---|
| Carbon | A | none | 28,000 | 60,200 | 0.47 | .. | ... |
| Steel | B | 0.078 | 80,000 | 88,800 | 0.90 | 45 | 190 |
| S. A. E. | C | 0.078 | 76,000 | 120,200 | 0.63 | 100 | 175 |
| 1020 | D | 0.078 | 70,000 | 130,300 | 0.54 | 115 | 150 |
| Laboratory No. 23 | E | 0.020 | 40,000 | 66,300 | 0.60 | 10 | 42 |
| | F | 0.020 | 60,000 | 87,900 | 0.68 | 46 | 115 |
| | G | 0.020 | 56,000 | 90,400 | 0.62 | 50 | 100 |
| Nickel | | | | | | | |
| Steel | A | none | 48,000 | 96,000 | 0.50 | .. | ... |
| S. A. E. | B | 0.025 | 98,000† | 187,500 | 0.53 | 95 | 105 |
| 2320 | C | 0.025 | 95,000† | 118,500 | 0.84 | 24 | 97 |
| Laboratory No. 24 | D | 0.025 | 100,000† | 107,000 | 0.94 | 12 | 108 |
| Chromium- | | | | | | | |
| nickel | A | none | 38,000 | 77,400 | 0.49 | .. | ... |
| Steel | B | 0.032 | 90,000† | 141,500 | 0.64 | 80 | 136 |
| S. A. E. | C | 0.032 | 85,000† | 102,000 | 0.83 | 31 | 123 |
| 3120 | D | 0.032 | 90,000† | 94,700 | 0.95 | 21 | 136 |
| Laboratory No. 25 | | | | | | | |

*Ratio of endurance limit to tensile strength.
†Estimated from data thus far obtained, tests still in progress.

for rolled steel, are seen to approach the horizontal as the stress is diminished. The estimated value of stress for which the S-N diagram becomes horizontal locates the endurance limit, or fatigue limit, for a metal. The values of endurance limit thus determined are given in Table V.

*Discussion of Results:* From Table V it is seen that carburizing followed by suitable heat treatment increased the fatigue

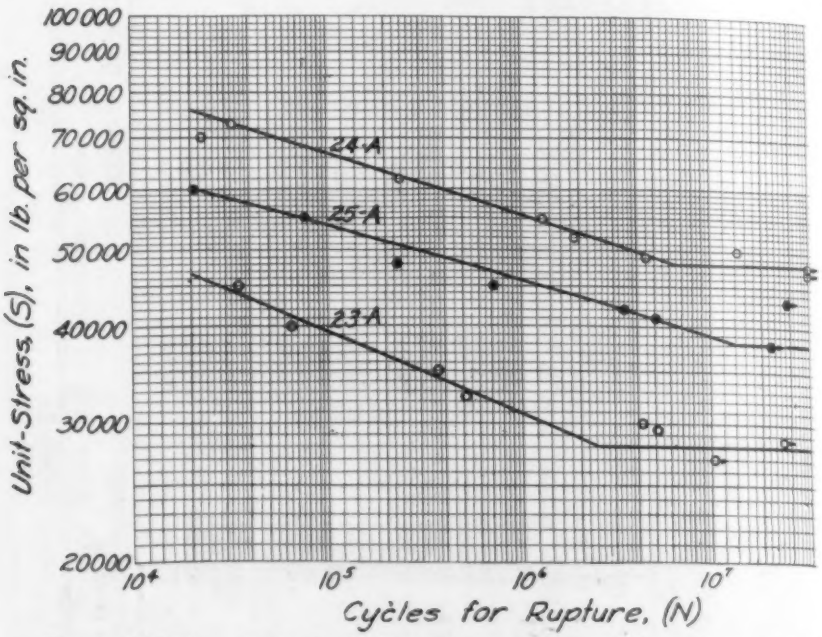


Fig. 8—S-N Diagram for Steels 23-a, 24-a and 25-a. Circle with an Arrow Denotes a Specimen Which Did Not Fail.

strength of the specimens tested, and that the tensile strength was also increased, but by a smaller percentage than the fatigue strength. In the tension test specimens the stress is more nearly uniform over the cross-section than is the case for the rotating-beam fatigue specimens, and the strength of the uncarburized core plays a more important part in determining the strength of a tensile specimen than is the case for a rotating-beam fatigue specimen, in which the outer part of the specimen is under a much greater stress than is the core. In other words, under bending (or torsion) carburizing and heat treating the surface of a specimen, or a machine part, adds strength where the bending stress is greatest, that is, at the surface, strength is added where most needed.

In the tests of the carbon steel (S. A. E. 1020, laboratory num-

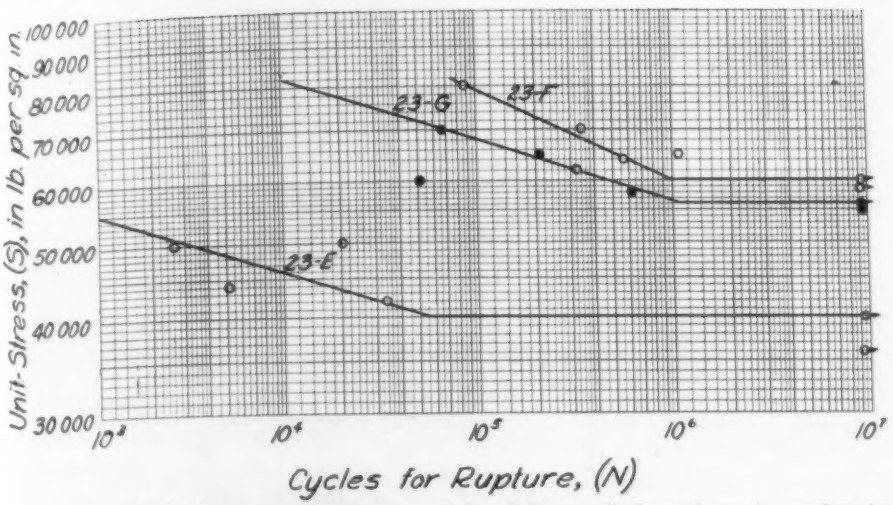


Fig. 9—S-N Diagram for Steels 23-e, 23-f and 23-g. Circle with an Arrow Denotes a Specimen Which Did Not Fail.

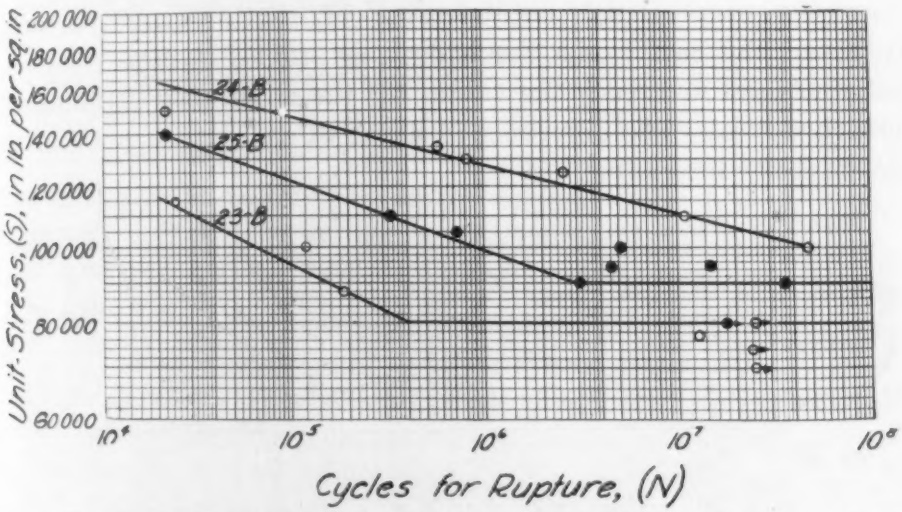


Fig. 10—S-N Diagram for Steels 23-b, 24-b and 25-b. Circle with an Arrow Denotes a Specimen Which Did Not Fail.

ber 23) some lots of steel were allowed to cool in the pot after carburizing. (Treatments E, F, and G.) In all other cases the steel was oil-quenched after carburizing. In the case of the steel allowed to cool in the carburizing pot the increase of fatigue strength due to carburizing was distinctly less than was the case for the specimens oil-quenched from the carburizing pot. The steels cooled in the pot were markedly improved in fatigue strength by subsequent refining treatments, the proportionate improvement due to the refining treatments being decidedly greater

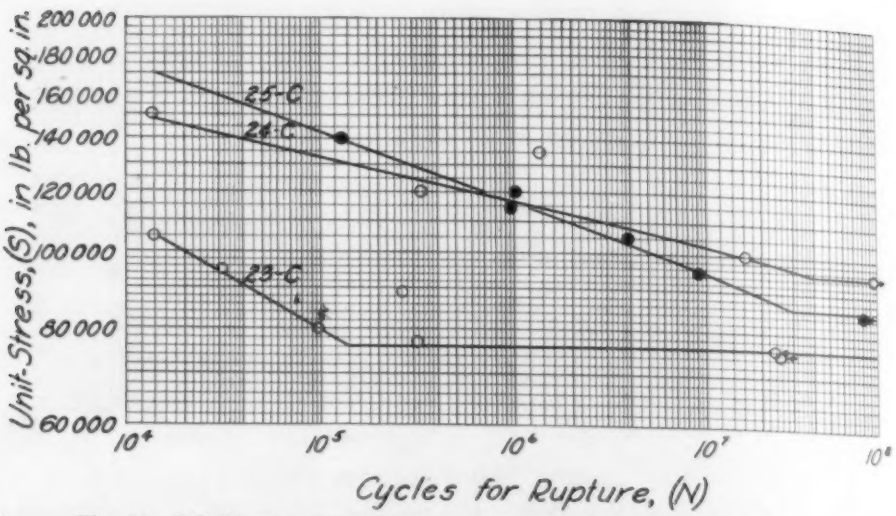


Fig. 11—S-N Diagram for Steels 23-c, 24-c and 25-c. Circle with an Arrow Denotes a Specimen Which Did Not Fail.

than the proportional improvement of the oil-quenched steel. However, the best values for endurance limit for these cooled-in-pot steels did not reach the values for the endurance limits of oil-quenched steel. The difference in depth of case makes quantitative comparisons impossible.

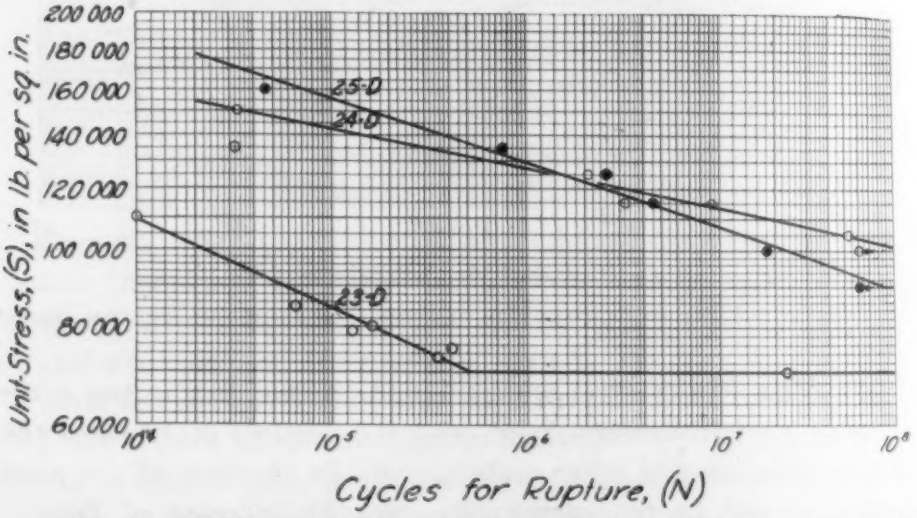


Fig. 12—S-N Diagram for Steels 23-d, 24-d and 25-d. Circle with an Arrow Denotes a Specimen Which Did Not Fail.

From Table V it is seen that for the carbon steel the greatest increase in fatigue strength is shown by the specimens quenched after carburizing and not subjected to subsequent refining heat treatment. For the nickel steel and the chromium-nickel there is

not much difference between the fatigue strength of the specimens tested with no treatment but carburizing and oil quenching and that of the specimens given subsequent heat treatment for refining the grain. However, the results shown in Table IV indicate that quenching carburized steel without a subsequent grain refining heat treatment diminshes the ductility of the steel, and, presumably, its resistance to shock.

If there is computed a stress equivalent to the strain at the outside of the core (inside of the case),—the idealized stress which may be supposed to exist where core and case meet—it will be found for all the steels tested that at the endurance limit this computed stress is higher, usually about 50 per cent higher, than the endurance limit of the virgin metal.

This would seem to indicate that at the outer edge of the core the strength of material is at least as great as is that of the virgin metal.

Fatigue tests under cycles of direct tension and compression have not yet been made on carburized steel. It would seem probable that such tests would show a smaller increase of fatigue strength due to carburizing than do rotating-beam fatigue tests, for reasons similar to those given in explanation of the comparatively small increase in static tensile strength due to carburizing.

A general idea of the increase in surface hardness of carburized steel may be obtained from the values given in Table IV.

In general, the test results suggest that carburizing followed by suitable heat treatment is a promising means of increasing the fatigue strength of steel under bending (or torsion) as well as an effective means of increasing surface hardness.

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## DISCUSSION

**Written Discussion:** By W. J. Merten, Westinghouse Electric and Manufacturing Co., Pittsburgh.

The problem underlying these experiments is a most interesting and important one from an engineering viewpoint and it was read by me with a very great deal of interest, especially in view of the fact that data and physical tests on carburized steels are very meager and fatigue values are probably not in existence at all, outside of those given by the author.

However, the information presented here lacks essential details of metallurgical character, rendering, therefore, any conclusions that may be drawn, very doubtful. The questions that immediately present themselves in the

reader's mind are pertaining to the character of the case, including concentration, carburizing method and measuring depth of case, and ratio of area of carburized section to that of the core or low carbon portion of the material.

An analysis of Table IV, showing depth of case and other physical characteristics of the test bars, cannot well be appreciated, unless some more definite data, relative to these questions, are presented therewith.

Microscopical analysis, carbon concentration and actual percentage composition of the case, with regard to carbon, obviously is of great importance for the study, and unfortunately, it is not in evidence. It seems to me that any one of the values given in the table lose their true significance, and certainly are not reliable data without further detailed analytical information of metallurgical character. The general tendency of case hardening of steels for the purpose of increasing the fatigue resisting properties is of such importance that even such preliminary information as is presented here, should prove a stimulus to the authors and other investigators, to supplement the information contained in this paper for the use of engineers in the design of apparatus, permitting him to make use of an ordinary low carbon steel or ordinary class of alloy steel by cementation with carbon to satisfy application in service under fatigue inducing stresses.

J. M. LESSELLS: Mr. Chairman, we are again indebted to Professor Moore for this further contribution to the fatigue of metals.

Regarding the point raised by him, I might mention that we have been running a nitrogen hardened steel, which, of course, is similar to the case hardened steel in that it possesses a hard outer surface under more or less ductile core at a stress of 56,000 pounds per square inch for 500,000 reversals without fracture. This, of course, is a higher value than could be expected from the same steel without the hardened outer surface.

JOHN MILLER: I think this is an important paper. It may interest the authors to know that the case hardening process has been successfully applied to semi-floating axle shafts on trucks. During the last year over 100 shafts have been placed in unusually severe service and no failures have resulted so far. The trucks are carrying loads of more than twice their rated capacity, and shafts made of high alloy medium carbon steel, treated in the usual way to 340-418 Brinell, fail by fatigue after 3000 to 10,000 miles. The case hardening process when properly applied, was found to be more effective in raising the strength, than increasing the section of the shaft considerably at the weak end.

During the last fifteen years there has been no great improvement made in the fatigue resisting qualities of steels. In 1913 we were using certain nickel-chromium steels and treatments, which gave fatigue strengths equal to the steels of today. Experience with the case hardening process on highly stressed parts, lead to the opinion that it may be of great importance to engineers in developing light cars of high endurance and performance.

It is not advisable to heat treat steels in the usual way much over 400 Brinell for highly stressed parts, because the internal stresses will be excessive. In case hardened steels the hardness can run over 600 Brinell on the case and

up to 400 on the low carbon core. In this way a very high elastic range may be produced where it is most beneficial and the internal stresses produced by quenching are of a low order. Also, even with 600 Brinell the case will permit of some plastic deformation and adjustment. For parts like front axles which are subject to accidental over strains, and which can be easily straightened, ductility is of great importance and case hardening would be entirely unsuitable.

E. J. P. FISHER: I would like to ask Mr. Miller whether the carburized steels were alloy steels or straight carbon steels.

JOHN MILLER: The steel used in the axle shafts contains 3½ per cent nickel, 1 per cent chromium and 0.18 per cent carbon. After carburizing they are reheated to 1470 degrees Fahr. and quenched in oil. The temper is not drawn. Experiments indicated that this treatment gives the best resistance to fatigue.

The usual double treatment to refine core and then the case is apt to have a softening effect on the core and does not seem to improve the fatigue resistance of the case.

PROF. H. F. MOORE: (Closure) The comments of Mr. Merten to the effect that the results given in this paper are not at all complete are quite true. However, his statement that any conclusions which may be drawn from this paper are very doubtful seems to the authors rather too strong a statement. One conclusion at least is fairly firmly established, namely, that case carburizing followed by suitable heat treatment can be used very effectively to increase the strength of steel. This conclusion is strongly reinforced by the remarks of Mr. Miller.

# WHAT HAPPENS WHEN HIGH SPEED STEEL IS QUENCHED

By B. H. De Long and F. R. Palmer

*Abstract*

*This paper deals with the metallography of high speed steel when tempered at 1100 degrees Fahr. after cooling during quenching to varying temperatures below 1300 degrees Fahr. The authors make the following observations:*

*1. High speed tools tempered (drawn) at 1100 degrees Fahr. before being allowed to become sufficiently cold in the quench are brittle due to mixed structures.*

*2. Straightening of high speed tools may be readily carried out during quenching at temperatures between approximately 1300 and 700 degrees Fahr.*

*3. A method is indicated for determining whether high speed tools have been quenched to a sufficiently low temperature before tempering.*

CENTURIES ago quenching was a mysterious art "understood" only by a chosen few. Such traditions as have come down to us through history attest that no formula was too complicated in those days to qualify as a suitable medium for quenching steel—even to the body of the poor Ethiopian slave through which the King's sword was plunged for purposes of quenching.

As metallurgical knowledge advanced, quenching graduated from an art to a science, and today it is common opinion that quenching is purely a question of speed of cooling. Some quenching baths cool rapidly and some cool more slowly; all that remains for the hardener is to select a medium which will quench his particular steel and tool at the proper rate in order to develop the necessary hardness. Partly because we believed that quenching was one of the simplest of all heat treating operations and partly because of the experimental difficulties involved in making observations during quenching, we have probably learned less of this important operation than any other step in the heat treating cycle.

A paper presented before the ninth annual convention of the society held in Detroit, September 19 to 23, 1927. Of the authors, who are members of the society, B. H. DeLong is metallurgist and F. R. Palmer is assistant metallurgist for the Carpenter Steel Company, Reading, Pa. Manuscript received June 18, 1927.

Strangely enough history is repeating itself, and we are beginning to uncover many mysteries involved in the quenching of steel which may have been suspected in the Dark Ages, but which have been completely overlooked in modern times. The story told in the following pages deals with just one of the many mysteries of quenching, and is concerned not with the mechanics of quenching high speed steel but rather with the structural changes taking place within the steel itself during the quenching operation.

The paper is confined entirely to a consideration of one type of high speed steel of the following nominal analysis:

| Carbon Per Cent | Tungsten Per Cent | Chromium Per Cent | Vanadium Per Cent |
|---|---|---|---|
| 0.70 | 18.00 | 3.50 | 1.10 |

In a steel of this type analysis there are two temperatures which seem to be of vital importance for the quenching operation, one around 1300 degrees Fahr. and the second around 700 degrees Fahr. Neither the exact location of these temperatures nor the factors which doubtless effect the exact location have been determined. However, the temperatures given are sufficiently accurate to enable their practical use.

As the steel is quenched past 1300 degrees Fahr. it becomes capable of hardening—it does not actually harden but simply acquires capacity to do so. As the steel cools through 700 degrees Fahr., hardening commences, and proceeds gradually to completion. It is only after 700 degrees Fahr. has been passed that the austenite is converted into martensite. The mechanics of this conversion are of interest and will be discussed later.

It should be realized that high speed steel will harden just as effectively when cooled freely in air as when quenched in oil. This fact makes the quenching of high speed steel much easier to observe than oil hardening or water hardening steels, since it is not necessary to have such accurate and elaborate apparatus for recording times and temperatures during quenching.

The curve shown in Fig. 1 illustrates the approximate Brinell hardness of high speed steel taken during the progress of air cooling or air quenching, however, no claims are made for the absolute accuracy of this curve. The values for the curve were secured by placing the thermocouple of an indicating pyrometer inside of a sample of high speed steel about 1¼ inches in diameter by 6 inches long. The piece was removed from the hardening furnace at 2300

degrees Fahr. and Brinell marks were placed on a flat spot on the cylinder periodically during the progress of quenching. Obviously the pyrometer on the inside of the piece did not exactly record the surface temperature at the point where the Brinell mark was placed. It is also obvious that the accuracy of the curve is greatest as the temperatures approach atmospheric.

It will be observed from the curve that the steel remains quite soft—about 210 Brinell down to a temperature of 700 degrees Fahr.

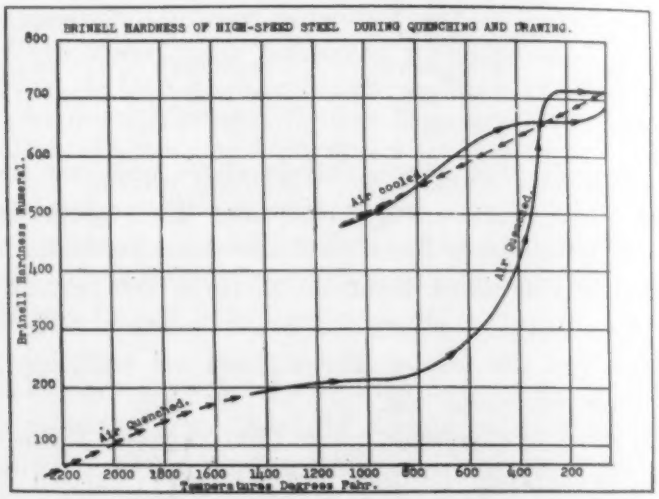


Fig. 1—Brinell Hardness of High Speed Steel During Quenching and Tempering.

This is approximately the hardness of annealed high speed steel and we get these low values because the steel has not yet begun to harden. As cooling progresses and the steel cools below 700 degrees Fahr. the steel begins to harden at an increasing rate attaining its maximum between 400 and 300 degrees Fahr. By the time the sample has cooled to 250 degrees Fahr. it is fully hard and shows the same Brinell readings as when it finally becomes cold.

It might be argued that the steel was soft above 700 degrees Fahr.—not because it had not hardened, but because it was still very hot. This is best answered by referring to the upper curve in the same figure. When the sample had reached room temperature it was placed in a lead tempering bath and allowed to remain for one hour. Hardness values were taken immediately upon removal from the lead and continuously during air cooling after the tempering operation.

The upper curve shows the hardness of properly hardened

high speed steel when reheated to 1100 degrees Fahr. to be approximately 475. The difference in Brinell hardness between the upper and lower curves at equal temperatures can only be accounted for by the fact that the steel had not hardened when the low values were recorded on the first curve. It is common practice to quench high speed steel from the superheating furnace into molten lead or molten salts maintained at about 1000 or 1100 degrees Fahr. and it is more or less generally believed that if the steels are held in

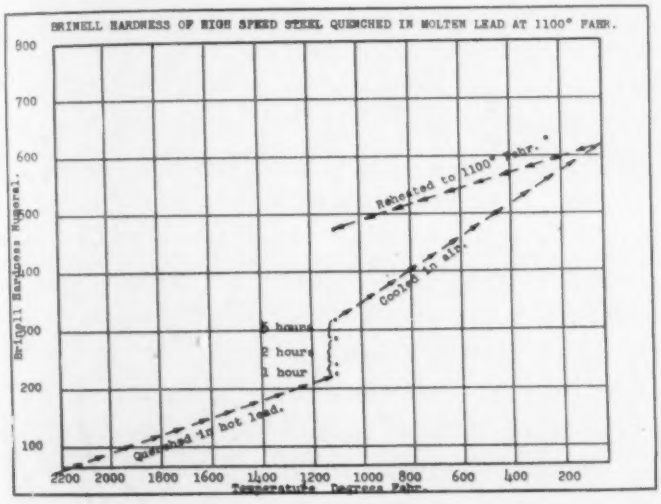


Fig. 2—Brinell Hardness of High Speed Steel Quenched in Molten Lead at 1100 Degrees Fahr.

this quenching bath for perhaps one hour and then cooled to room temperature that they have been properly hardened and tempered.

Obviously no steel can be tempered until it has first been hardened, and if we interrupt the quench between approximately 1300 degrees Fahr. and approximately 700 degrees Fahr., we are holding the steel in its austenitic or unhardened condition and consequently there can be no tempering effect. This is shown by referring to the curve in Fig. 2. In this case a sample similar in every way to that described above was quenched directly from the superheating furnace at 2300 degrees Fahr. into a molten lead bath maintained at 1100 degrees Fahr. After three minutes in the lead, a Brinell hardness was quickly taken and a value of 223 obtained. The sample was quickly replaced in the lead and allowed to soak for one hour at heat, after which a second Brinell mark was placed beside the first. This mark read 241 Brinell. The sample was quickly replaced in the lead and Brinelled again after two hours

additional soaking, yielding a Brinell hardness of 286 and was then immediately given five hours more in the lead, after which the Brinell was 315. These points are shown on the chart in Fig. 2 and prove that even after eight hours continuous immersion, the steel has not yet fully hardened, and it is doubtful whether it would ever do so. No explanation is offered for the gradual increase in hardness during this 8-hour soak at 1100 degrees Fahr. It is suggested as a possibility that the sample may have cooled sufficiently each time the Brinell hardness was taken to have permitted a slight degree of hardening to take place.

The data shown in Fig. 2 indicates that high speed steel when quenched into a molten bath requires tempering just the same as though it were quenched directly to room temperature without any interruption. It is most probable that lead-quenched and salt-quenched tools are not as highly strained as tools quenched continuously to room temperature, but from a metallographic, or structural standpoint, the net result is exactly the same.

In hardening high speed steel the importance of not quenching the tools stone cold has always been emphasized—and justly so. There is nothing more likely to cause tools to crack than the practice of quenching them absolutely cold in oil and then allowing them to lie around for some time before tempering. This is an extremely dangerous practice and is emphasized at this point for fear some of the following statements may be misconstrued. It is, however, a fact that high speed steel must be quenched down to a certain temperature before tempering or else the tool will be brittle and unreliable and extremely likely to spall or chip in service. Many unexplained failures in high speed tools can be traced to their removal from the quenching bath at too high a temperature and then attempting to temper them before the steel has fully hardened.

Fig. 3 illustrates the normal average microstructure of high speed steel in the condition as quenched from about 2300 to 2350 degrees Fahr. The structure consists of polyhedral grains which appear white after etching in 2 per cent nital. Within the grains are imbedded undissolved particles of carbide which were not dissolved during hardening. The present paper is not in the least concerned with these carbides, and, although they will appear in all of the photomicrographs, no further mention will be made of them.

Fig. 4 illustrates a typical structure of the same piece of hard-

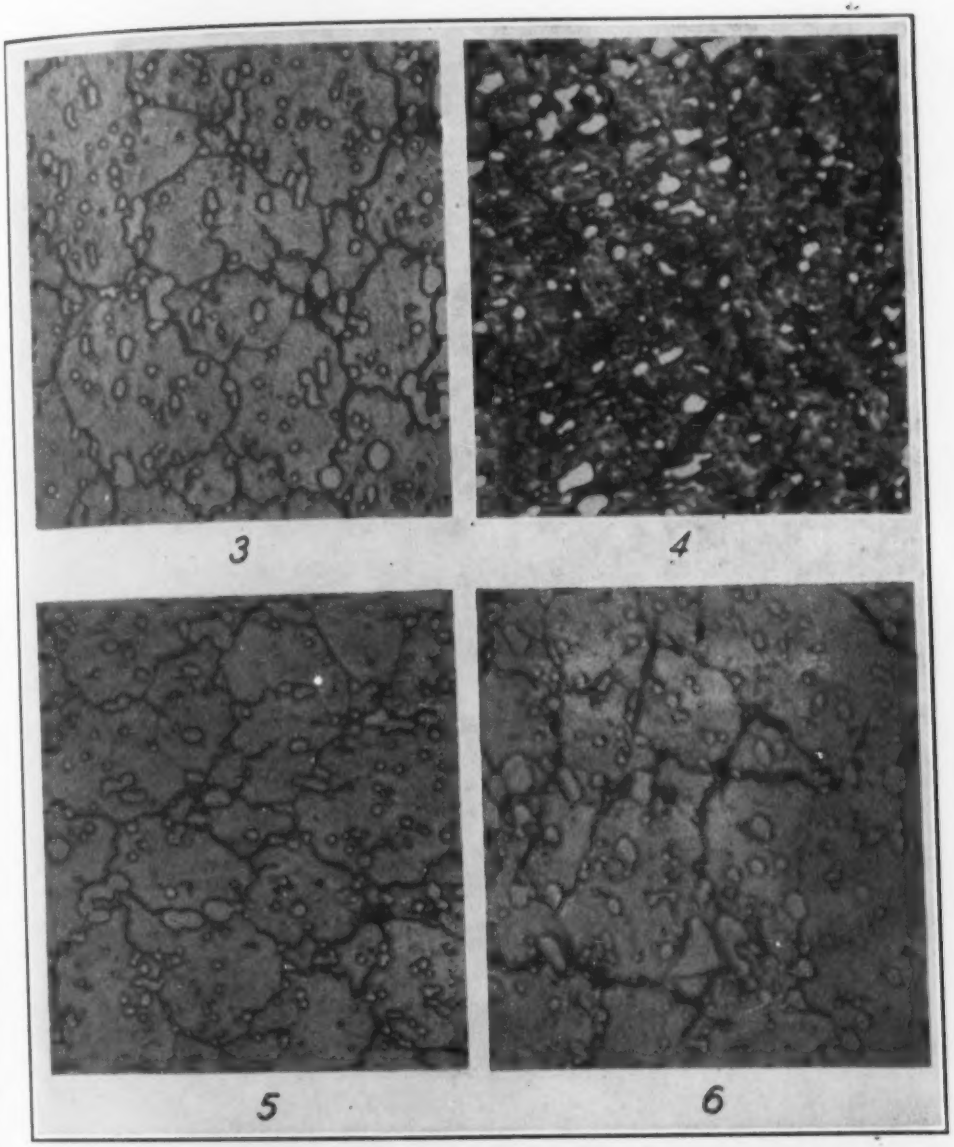


Fig. 3—Normal Average Microstructure of High Speed Steel as Quenched from 2300-2350 Degrees Fahr. Etched in 2 Per Cent Nital. 1000 x Fig. 4—Photomicrograph Showing Typical Structure of Same Piece as Fig. 3 After Being Tempered for 1 Hour at 1100 Degrees Fahr. Etched in 2 Per Cent Nital. 1000 x. Fig. 5—Photomicrograph of the Structure of the Hot End of the Specimen. This Did Not Reach a Temperature Lower Than 1100 Degrees Fahr. Etched in 2 Per Cent Nital. 1000 x. Fig. 6—Photomicrograph of the Structure Where Hardening Has Just Commenced. Etched in 2 Per Cent Nital. 1000 x.

ened high speed steel after it has been tempered for one hour at 1100 degrees Fahr. The hardened material within the grains has been so changed by the tempering operation that it now etches very darkly when immersed in 2 per cent nital. Thus it is easy for the metallographist to tell whether a piece of high speed steel has

been tempered at 1100 degrees Fahr. or not—the difference is simply that between black and white.

Let us now refer to the curve in Fig. 1 and consider what would happen if high speed steel is withdrawn from the quenching bath anywhere between 700 degrees Fahr. and 300 degrees Fahr. and then immediately placed in a tempering bath and tempered at 1100 degrees Fahr. This leads to a metallographic study which will explain many mysterious high speed steel failures. It must be borne in mind that high speed steel will harden just as effectively in air as it does in oil and that the structure will be identical when viewed under the microscope regardless of which method of quenching is used. Let us consider a simple experiment.

A sample of high speed steel measuring 1 x ¼ inches by about 10 inches long is heated to 2300 degrees Fahr. It is then held in the tongs by one end and the other end is placed just below the surface of an oil quenching bath. The piece is moved back and forth rapidly in the oil, being gradually immersed deeper and deeper. There comes a time when the sample is say one-half immersed, and the portion exposed in air has cooled to a black red heat of about 1100 degrees Fahr. By this time the point of the sample which went into the oil first is practically cold, so that it can just about be touched with the bare hand. If the extreme point is practically cold and the part which has not yet been placed in oil is 1100 degrees Fahr. in between these two extremes there must be every possible intermediate temperature.

At this stage the sample is quickly transferred to a lead tempering bath held at 1100 degrees Fahr. In this experiment we have interrupted the quench—somewhere along the bar—at every possible point between room temperature and 1100 degrees Fahr. and have immediately tempered the sample. By splitting this piece longitudinally through the center and polishing the section for microscopic examination, we find traced along its length the complete history of what happens when high speed steel is tempered at 1100 degrees Fahr. after quenching to all temperatures below approximately 1100 degrees Fahr. Figs. 5 to 11 inclusive are photomicrographs taken along the length of this test specimen.

Fig. 5 shows the structure at the hot end. Since this point did not get below approximately 1100 degrees Fahr. on the quench, it did not start to harden and therefore received no influence whatever

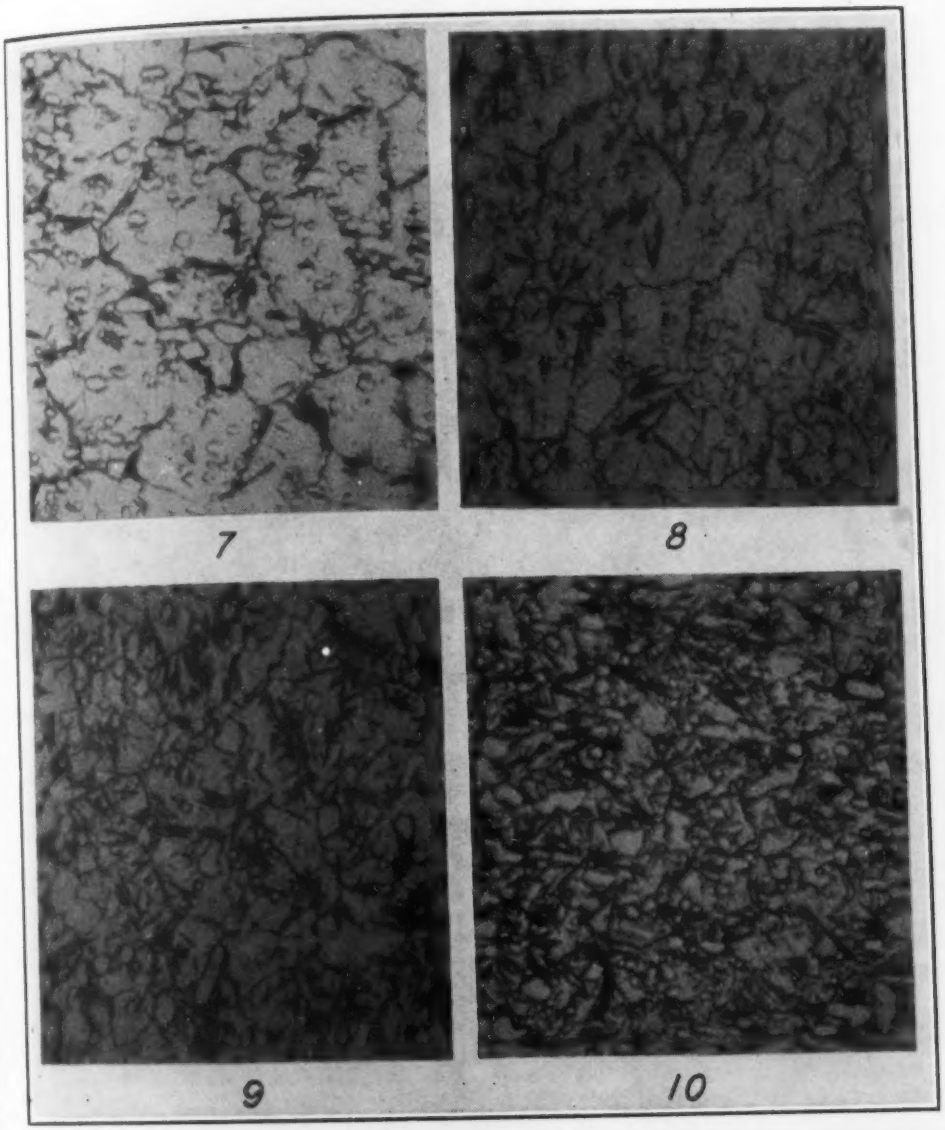


Fig. 7—Photomicrograph of the Structure Slightly Closer to the Cold End. Etched in 2 Per Cent Nital. 1000 x. Figs. 8, 9, 10—Photomicrographs Showing the Structures of the Next Three Samples Progressing Toward the Cold End. Etched in 2 Per Cent Nital. 1000 x.

from the temper at 1100 degrees Fahr. Hence we have a typical hardened and untempered structure. Of course the piece hardened for the first time while it was cooling in air after tempering. Fig. 6 illustrates the structure where hardening has just commenced. It will be noticed that the steel starts to harden in the grain boundaries giving the effect of relatively dark broad lines (we know that these dark lines must have hardened during the quench, otherwise they would not become dark upon etching after the tempering operation.)

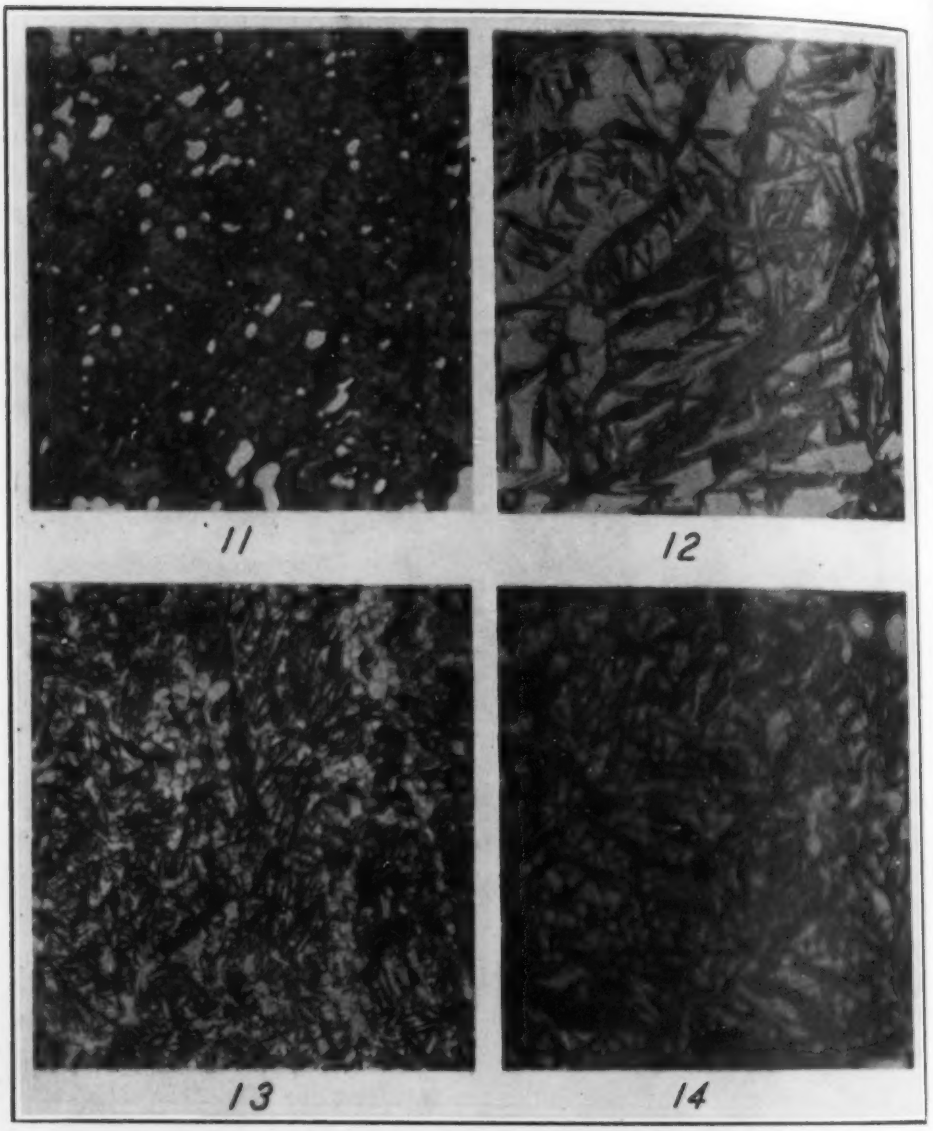


**Fig. 11—Photomicrograph of the Structure of the Cold End of the Bar Where Hardening Has Progressed to Completion. Etched in 2 Per Cent Nital. 1000 x. Figs. 12, 13, 14—Photomicrographs of the Structure of Three High Speed Milling Cutters Which Failed in Service. Etched in 2 Per Cent Nital. 1000 x.**

Fig. 7 shows the structure slightly closer to the cold end, and it will be seen that the next step in hardening is for martensitic needles to grow from the grain boundaries into the various grains. Figs. 8, 9 and 10 represent the next three steps as we progress toward the cold end. The needles are increasing in length and increasing in number. Fig. 11 was taken at the cold end of the bar where the hardening progressed to completion during the quench.

The structures illustrated in Figs. 6 to 10 have frequently been observed on high speed tools which have cracked or chipped in service and have been variously ascribed to poor steel, overheat in hardening, overheat in forging or rolling, poor annealing, etc. Figs. 12, 13 and 14 represent actual photomicrographs of the structure in three high speed milling cutters which failed in service due to the teeth breaking out. It is not difficult in the light of our experiment to explain the failure in these tools. It is the authors' opinion that high speed steel containing this mixed structure is more brittle than would have been the case had the tools never been tempered at all. If a tool is hardened and not tempered we at least have a certain degree of uniformity, but if the tool is only partially hardened when it is tempered, we get a mixed structure, which is extremely brittle.

There are a number of purely practical suggestions to be taken from this study:

Since there is a spread of about 600 degrees Fahr. between the temperature where high speed steel first makes up its mind to harden (approximately 1300 degrees Fahr.) and the time when it actually starts to harden (approximately 700 degrees Fahr.), there is ample opportunity within this range for the hardener to straighten or otherwise form high speed tools during quenching. This is particularly valuable in the case of long reamers, taps, shear blades, and other tools. The steel may be safely and easily bent between these two temperatures during the quench.

Further, since high speed steel tools are in no danger of cracking until they start to harden, and since the speed of cooling through the actual hardening range below 700 degrees Fahr. is unimportant, there is really little reason for cracking high speed tools. They can be quenched in oil down to approximately the flash point, and then removed from the oil and cooled in air, in which case there is not set up any more strains during hardening than as though the tools had been air-quenched right out of the superheating furnace. This can also be nicely taken care of by quenching into lead or molten salts followed by cooling in either air or lime.

The hardener must realize that there is an upper limit as well as a lower limit to the temperature where quenching should cease and tempering should begin. On the one hand he must avoid allowing the tools to become stone cold before tempering. On the other

hand, they should get down sufficiently cold so that they will scarcely boil a drop of water placed on the surface. A good average temperature is that at which the tools can be just about juggled in the bare hand.

These data should be of interest to the metallographist since it enables him to examine any tool which has been tempered in the high range (950 to 1150 degrees Fahr.) and tell approximately how cold it was allowed to become before tempering.

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## DISCUSSION

**Written Discussion:** By O. Z. Klopsch, Wolverine Tube Co., Detroit.

This paper should be interesting and instructive to both the practical and technical man. The method of attack is novel and apparently the results obtained are practically correct.

The authors give two temperatures which are of importance, 1300 and 700 degrees Fahr., however, no mention is made of how the 1300-degree Fahr. temperature was obtained and it would be interesting to know how they arrived at it.

On discussing the "Brinell Hardness of High Speed Steel During Quenching and Tempering" they state that "It will be observed from the curve that the steel remains quite soft—about 210 Brinell down to a temperature of 700 degrees Fahr. This is approximately the hardness of annealed high speed steel and we get these low values because the steel has not yet begun to harden." I believe a word of caution should be given here as the second sentence might infer that since the hardnesses are the same the nature of the steel on cooling is the same as annealed high speed steel. We know that on cooling in this range the steel is probably entirely austenitic while in the annealed condition it is, of course, in the alpha condition.

I do not believe that the authors have proven that the steel will not harden when held at 1100 degrees Fahr. for a considerable length of time. They have certainly shown that it would not harden appreciately in any practical period of time. In view of the fact that it takes at least a minute or two to cool the surface of such a specimen from 1100 to 700 degrees Fahr., I do not believe that they can attribute a hardening of 100 points Brinell to such cooling.

The authors' statements regarding the metallographic features are very interesting and valuable. They serve as a real addition to the applications of the art of metallographic examination. In examining the photomicrographs of samples 5 to 11 and observing the gradual increase in the amount of martensite as the cold end of the sample is being approached, the question enters the writer's mind if a similar phenomena might not have been observed in the sample held at 1100 degrees Fahr. for periods of time from 1 to 8 hours. In other words, might not the austenite to martensite change in high speed steel also be partially controlled by the time factor? From the increasing values of hardness the authors obtained with time, and the fact that

at this temperature the martensite phase is nearer the stable equilibrium than austenite, one might draw such a conclusion.

As to the three failed samples shown, one cannot, however, help but wonder if this structure might not also be caused by other means, such as by tempering for too short a period or by overheating in the initial quench. It would be quite interesting to know if another tempering operation would make this structure all martensitic as desired.

One other point of decided interest is the authors' statements regarding brittleness due to mixed structures. This brings to mind the many curves shown on alloy steels and for that matter some carbon steels which show a drop in impact values as the steels are tempered in the neighborhood of 700-800 degrees Fahr. where a mixed structure of either austenite and martensite, or martensite and troostite might well be present. Might their explanation not serve as a cause for this phenomena?

**Written Discussion:** By Zay Jeffries, Cleveland.

The authors are to be congratulated for designing a test procedure which so clearly shows the behavior of high speed steel, when subjected to certain heat treatments. Their results are consistent with much information now available and proof is offered of the important points pertaining to the temperatures at which the various changes occur. In particular the evidence that the acicular martensite forms quickly during cooling when the proper temperature range is reached and that the austenite retains a substantial degree of stability somewhat above the temperature at which martensite begins to form is very gratifying. This is what the work of Portevin and Garvin, Chapin, French and others would lead us to expect but no one so far as I know, has made such a pretty demonstration of it before.

With reference to the hardening at about 600 degrees Cent. mentioned by the authors and by Klopsch in his discussion, this seems to me to be entirely similar to the slow hardening of austenitic manganese steel at say, 500 degrees Cent. The high speed steel austenite is super-saturated in carbon, tungsten and perhaps chromium. There is a strong tendency for the double carbide to precipitate from the super-saturated austenite. Any double carbide precipitated at this temperature would necessarily be in minute particles, which would increase the hardness. Furthermore, the precipitation of some double carbide would impoverish the austenite in carbon and tungsten and perhaps the other elements present and would make it more unstable thus promoting the transformation in part to alpha iron. Such austenite as may transform should produce additional hardness because at 600 degrees Cent. the transformation should be to troostite which is harder than the austenite.

A. H. d'ARCAMBAL: Some months ago we conducted an experiment on a few high speed steel cutting-off blades coming through the shop. These blades were quenched from 2340 degrees Fahr. into a lead bath maintained at 1100 degrees Fahr. After being allowed to remain in the lead for a few minutes, they were put into a vice and bent in all directions without any difficulty whatsoever. They were immediately taken from the vise and tested

for Rockwell hardness, showing a Rockwell of C-10 to 15. These blades were then allowed to cool to room temperature and again tested for Rockwell hardness, showing a Rockwell of C-65 to C-66 and were, of course, file-hard. We attempted to bend the blades again and, as expected, they snapped off, being very brittle. The same blades were placed in the lead bath at 1100 degrees Fahr., held there for about thirty minutes, taken out and again placed in the vise and they snapped off without taking a bend. They were tested for Rockwell hardness and showed a hardness of C-59 to 60. They were then allowed to cool to room temperature, showing a Rockwell of C-63 to 64 and were file-hard. These blades broke without taking any preceptible bend but were more or less springy.

We have used this application for the straightening of long, high speed steel tools, but unfortunately, tools straightened when taken out of the quench at 800 to 1000 degrees Fahr., do not remain straight when cooled to room temperature, but again have to be straightened; and, finally, after the high temperature, it is necessary to straighten these tools again, this being the toughest part of the job because the correctly hardened tools are quite springy and it is very difficult to straighten them.

The authors brought out the point that high speed steel tools should not be allowed to become cold before they were tempered. Now, that is perfectly all right in shops hardening only a few high speed tools daily, but where you harden thousands of high speed steel tools daily, it will not work out from a production standpoint. In fact, I have known a good many cases where we allowed tools quenched, say, at 3:00 or 4:00 o'clock in the afternoon to remain in the hardening room until the next morning. We can trace no cracking loss due to the fact that these tools are allowed to become cold before being tempered.

J. V. EMMONS: Mr. DeLong and Mr. Palmer are to be commended for this very excellent paper. There is, however, one statement which is contrary to my experience and to which I would like to call attention, "That high speed steel will harden just as effectively when cooled freely in air as when quenched in oil."

A certain degree of rapidity of cooling is necessary to harden all tool steels including high speed steel. The fact that high speed steel has a slower critical rate of cooling than most of the other types makes it possible to harden small sizes in air under certain conditions. As the size of the tool increases, an increase in the rate of cooling becomes necessary. More drastic quenches can be obtained by the use of air blast, oil or by the use of molten baths of lead or salts.

O. Z. KLOPSCH: Just previous to coming down to the convention, we took a piece of high speed steel of the same size and shape as Mr. Palmer used and heated it to about 2250 degrees Fahr. and then put it in a furnace at 1100 degrees Fahr. and left it there a total time of seventy hours to see whether we would get any increased hardness with time. As I mentioned in my written discussion, we found out several things that I think are of interest and would indicate that there is a change going on at 1100 degrees Fahr. You will remember Mr. Palmer's paper; at 1100 degrees Fahr., on cooling, he had a

hardness of about 220. After he allowed it to cool all the way through air, the Brinell was up to in the neighborhood of 700.

Then, another sample was held at 1100 degrees Fahr. for different periods of time and was allowed to cool to room temperature, and the way I remember it, the hardness was a few points less than 700. The sample that we took, we obtained no reading as we put it in the furnace, unfortunately, but after 23 hours we got a Brinell hardness of 255. The time required to take the sample out of the furnace until we put it back in after making our hardness reading was around forty seconds, and according to our calculations on air cooling from 1100 down to 700 degrees Fahr., as far as air cooling itself is concerned is about a minute and a half to two minutes. Of course, the question of the ball itself conducting away the heat may account for the increased hardness and at the end of 70 hours we had a hardness of 286. On allowing that sample to cool in air, after 70 hours at 1100 degrees Fahr., we had a Brinell hardness of only 550 (Rockwell C-55), and on re-heating it to 1100 degrees Fahr., as Mr. Palmer did, and taking the hardness at 1100 degrees Fahr. again, we had a Brinell of only 375 as against about 475 that he had. We examined the sample with a microscope and apparently what we found confirms the hardness we obtained.

In other words, we had a martensitic structure, but it appeared that around the grains there was a still darker and blacker constituent appearing which looked to us somewhat like tempered martensite.

In view of the above, apparently if the time at 1100 degrees Fahr. were carried out long enough, we would get even less than 550 Brinell; we might have a soft steel in perhaps a month. I think the transformation from austenite right straight through to alpha iron would occur at 1100 degrees Fahr. if it were held there a long enough period of time.

In order to ascertain if the method used in endeavoring to hold the heat in the sample by taking it, packed in silocel powder, from the high speed steel furnace to the rather far removed 1100 degrees Fahr. tempering furnace, another sample of the same size and shape was treated in identically the same way as the sample previously discussed. This new sample, however, was only permitted to remain for one-half hour at 1100 degrees Fahr. whereas the first sample was at temperature 70 hours, previous to air cooling. The hardness obtained was 652 Brinell or 64 Rockwell "C." Comparing these values with the 550 Brinell or 55 Rockwell "C" obtained on the other sample, indicates not only that the one half hour sample became almost full hard, perhaps it was full hard within the limits of accuracy of such hardness readings, but also that the 70-hour sample was made considerably softer by its treatment.

The reason as to why the sample was hard even though cooled in silocel is quite evident when it is borne in mind that the sample was removed from the silocel when it was still a bright cherry red, about 1600 degrees Fahr., and then allowed to cool through the 1300-degree Fahr. transformation in a 1100-degree Fahr. furnace, which is much faster than cooling in silocel.

F. R. PALMER: We wish to thank these gentlemen for contributing this

discussion. Mr. Klopsch has brought out some points that are very important. I do not know how we came to omit the method for establishing the 1300-degree critical point unless because the temperature was determined several years before the lower one and was regarded around the shop as common knowledge. It was determined in a somewhat similar method; a lead pot was heated up to about 1600 degrees Fahr. and a series of samples were heated in a high speed hardening furnace. The power was then shut off the lead and it was allowed to cool slowly. As it went past, say 1600 degrees Fahr., a sample was taken out of the high speed furnace and placed in the lead, at 1550 degrees Fahr. another sample would be taken, and so on as the lead pot cooled down additional samples were taken and placed in it. Obviously, the sample which went into the lead above the "promise" temperature became soft, because they were cooled slowly through that temperature. Those which went into the lead below this temperature became hard because they got the benefit of lead quenching down to that point. I am glad Mr. Klopsch brought the point up, because it is important.

Referring to one of the comments in a later paragraph in Mr. Klopsch's discussion, we did take some of these needle-like structures which had a white background and re-tempered them at 1100 degrees Fahr., and they became black all over. This disproves the possibility that this structure might be due to overheat or too short a time in tempering, etc.

I will not take issue with Mr. d'Arcambal about letting high speed tools get cold; that is up to the individual hardener. There have been a lot of dramatic failures due to allowing large high speed tools lay over night without tempering them. It is for the hardener to decide whether he wants to leave them lay or wants to get them in the tempering bath. It is, however, a dangerous practice. It is much the same as oiling shafting when it is in motion; a fellow may get away with it for many years, but some day he gets wrapped around the shaft and that is the end of it.

In responding to Mr. Klopsch's final contribution, we are glad to have these facts because they bear out some of the points. Regarding his tests, I understand that the hardening furnace was quite remote from the lead pot and that the piece was carried from the hardening furnace to the lead pot in silocel. I would suggest as an explanation for his low hardness values, that he got slow cooling through the $Ar_1$ due to the fact that the piece was not air-cooled but cooled in silocel, and that his low hardness readings are not due to the fact that he held it seventy hours at 1100 degrees Fahr.

I would also submit that slow cooling through the upper critical might explain the apparent troostitic grain boundaries. We know in carbon tool steels and other steel that we examine under the microscope that when you cool a piece of steel just under its critical quenching speed, just too slow to harden, you begin to get troostite in the grain boundaries. The black constituent shown in these photomicrographs in the paper is not troostite, it is the tempered martensitic structure characteristic of high speed steel when tempered in the high range. So if his constituent is troostite, I think that would point to the likelihood of slow cooling through the upper critical rather than prolonged holding between the upper and lower critical.

# ARMCO INGOT IRON—Part II

By Reid L. Kenyon

*Abstract*

*Armco ingot iron is the trade name for commercially pure iron produced in the basic open-hearth furnace. The product has now been on the market for several years and has become useful in many industries. Due to its high degree purity it has been used in many scientific investigations where pure iron has been required.*

*References to Armco ingot iron or "Armco Iron," in the literature are many. It has been tested and experimented upon in all manner of ways, but no attempt has yet been made to compile and coordinate the vast amount of data that has accumulated from the work of various investigators upon this material. In addition to references to published results of various investigators, this paper also presents numerous data from unpublished work of the research department of the American Rolling Mill Company.*

*The scope of the paper includes a description of the material, its chemical analysis, its microstructure after various treatments and the effect of mechanical work and heat treatment on its various physical properties. This data is given for Armco ingot iron in the form of hot-rolled and cold-rolled bars and shapes, plates, sheets, and wire. The tests reported include tension, compression, shearing, impact, hardness, and fatigue tests of various kinds.*

THIS paper by Reid L. Kenyon was presented by the author before the ninth annual convention of the society held in Detroit, September 19 to 23, 1927. Due to the length of the paper it has been necessary to publish it in two successive issues of TRANSACTIONS. The first part of the paper appeared on pages 240 to 269 of the February 1928 issue of TRANSACTIONS and discussed composition, method of manufacture, microstructure, physical, electrical and tensile properties of bars and sheets. A complete discussion of these various properties is made and many data both in chart and tabular form are included.—Editor.

This paper is based on a thesis submitted by Reid L. Kenyon in partial fulfillment of the requirements of Purdue University for the degree of Chemical Engineer, June, 1927.

A paper presented before the ninth annual convention of the Society held in Detroit, September 19 to 23, 1927. The author, R. L. Kenyon is research associate, American Rolling Mill Co., Middletown, Ohio.

## Hardness

A number of different methods have been devised for determining the relative hardness of metallic materials but only a few have come into general use. The Brinell, the scleroscope and the

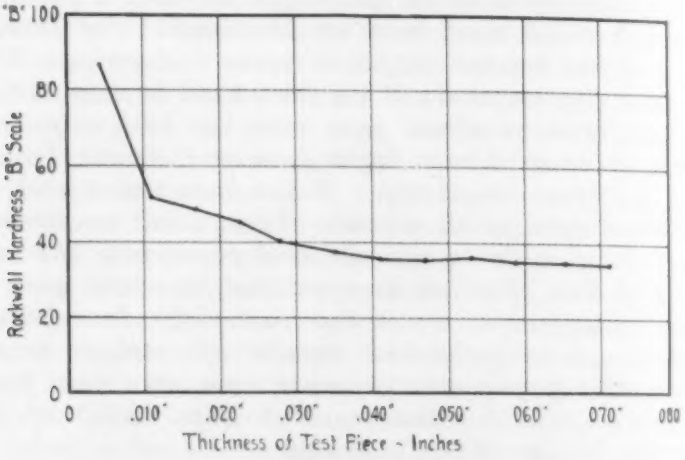


Fig. 27—Curve Showing the Effect of Gage on the Rockwell Hardness of Light Gage Armco Ingot Iron Sheets. Rockwell Hardness of Anvil C-55 (505 Brinell). Unpublished Investigation, Research Laboratory, American Rolling Mill Company.

Rockwell tests are the ones most widely used at the present time. Each has its advantages and disadvantages and all have their limitations. All points considered, the Rockwell tester comes nearer meeting all requirements for testing thin sheet than any other hardness test (46) now in common use. This method was used in making the hardness tests presented in this paper.

**Table IX**

**Minimum Thickness of Material on Which Brinell Tests can be Made so That the Thickness Equals Ten Times the Depth of the Brinell Impression**

| When the Brinell Hardness is— | The approximate thickness of the test specimen must be at least |
|---|---|
| 70 | 9/16 inches |
| 80 | 15/32 inches |
| 90 | 7/16 inches |
| 100 | 13/32 inches |
| 125 | 5/16 inches |
| 150 | 1/4 inches |
| 200 | 3/16 inches |
| 300 | 1/8 inches |

On account of the wide usage of the three different types of hardness tests, the desirability of conversion of results from one system to another is readily apparent. A good deal of work has been done on this question and it has been found that the exact relationships between the different hardness scales varies somewhat with different materials. Any general-purpose conversions (80) must therefore be taken only as approximations and for accurate conversions a series of tests should be made on the particular material in question.

### Hardness Tests on Various Shapes of Armco Ingot Iron

The hardness of Armco ingot iron depends on the mechanical work and heat treatment which it has had. In this respect the property of hardness resembles tensile strength, yield point, etc., for all of these quantities are affected by these variables. The effect of cold work on tensile properties and hardness of ingot iron has already been discussed and it was shown that the Rockwell hardness varied from B-30 to B-65. This is equivalent to a Brinell range of 74 to 117. By excessive cold working the Rockwell hardness can be increased to B-80 to B-85 which is equivalent to 151 to 165 Brinell. On the other hand, extremely soft samples will sometimes test as low as B-20 or 67 Brinell.

Rockwell hardness tests on a number of hot-rolled Armco ingot iron plates of various gages cover a range of B-37 to B-56. These are extreme values between which the hardness of this form of Armco ingot iron may be expected to run. This variation is due to difference in gage, difference in finishing temperature, etc.

Some results on the hardness of hot-rolled rods were presented under the heading of tensile properties of this class of ma-

**Table X**
**Hardness of Armco Ingot Iron Hot-Rolled Rods**

| Size Inches Round | Average Rockwell Hardness | Brinell Hardness by conversion from Rockwell averages |
|---|---|---|
| 3/8 | B-54.5 | 100 |
| 1/2 | B-46 | 89 |
| 5/8 | B-45 | 88 |
| 3/4 | B-46 | 89 |
| 7/8 | B-39 | 82 |

terial. These rods varied from 3/8 to 7/8 inch and it was found that in a general way the hardness increased as the size decreased. This is doubtless due to the fact that the smaller sizes are finished colder than the larger ones. This would naturally increase the hardness due to the increased amount of cold working. Table X gives the averages of a number of hardness tests on different bars of each size.

**Table XI**
**Hardness of Armco Ingot Iron Hot-Rolled Shapes**

| Size Inches | Rockwell hardness by conversion from Average Brinell | Average Brinell Hardness |
|---|---|---|
| 11/16 x 5/16 | B-47 | 90 |
| 13/16 x 5/16 | B-46 | 89 |
| 1/2 x 1 | B-47 | 90 |
| 1/2 Round | B-43 | 86 |
| 23/32 Round | B-43 | 86 |
| 9/16 Round | B-46 | 89 |

Hardness tests on another lot of hot-rolled Armco ingot iron rods of various shapes and sizes gave the results found in Table XI.

It is impractical to make any except the Rockwell hardness tests on small diameter wires. Even with this test it is necessary to file a small flat spot in order to eliminate the error due to the curvature of the surface. The Rockwell hardness of Armco ingot iron wire will depend on whether it is soft annealed or hard drawn, the same comments applying here as were given under tensile tests on this class of material. Soft annealed wire will run as low as B-30 while the hard drawn will be about B-65 to B-70.

Under a separate heading a discussion was given to tensile tests made on Armco ingot iron forgings that had been subjected

**Table XII**
**Rockwell Hardness of Different Grades of Armco Ingot Iron Sheets**

| Grade | Average Rockwell Hardness |
|---|---|
| Armco Ingot Iron "Black" | B-36 |
| Armco Ingot Iron "Blue Annealed" | B-53 |
| Armco Ingot Iron "Galvanized" | B-51 |
| Armco Ingot Iron Enameling stock for flat work and light draws | B-32 |
| Armco Ingot Iron enameling stock | B-40 |

**Table XIII**

**Brinell Hardness of Heat Treated Armco Ingot Iron Forgings**

| Bar No. | Heat Treatment | Average Brinell Hardness |
|---|---|---|
| 1 | As forged, finished cold | 101 |
| 2 | As forged, finished hot | 90 |
| 3 | Finished hot, annealed 25 hrs. at 1650° F. slow cooled | 82 |
| 4 | Finished hot, air cooled from 1725° F. | 92 |
| 5 | Finished hot, water quenched from 1725° F. | 110 |
| 6 | Finished hot, water quenched from 1725° F., reheated to 1200° F., air cooled | 94 |
| 7 | Finished hot, annealed 2½ hrs. at 1650° F., fairly slow cooled (more rapid than No. 3) | 87 |

to various heat treatments. These same samples were used for Brinell hardness tests and the results are given in Table XIII.

Bar No. 3 which received a long time annealing and slow cooling is the softest, while the water quenched material is the hardest. As pointed out in the discussion of the tensile tests on these samples, the greater hardness of the water-quenched bar is due to the fine ferrite grain structure produced by the sudden cooling and not by any hardening process similar to that which takes place in quenching carbon steels.

It is interesting to note that practically the same Brinell hardness for quenched Armco ingot iron was reported by the University of Illinois Engineering Experiment Station (49) in connection with fatigue tests on metals (see summary of these results). They quenched from 1500 degrees Fahr. and found the Brinell hardness increased from 69 to 109.

*Impact Strength*—Where toughness and resilience are necessary properties, the impact test has come to be recognized as the best means of comparison. Various types of impact tests have been proposed by various investigators but most testing of this kind consists of a bending test made on a "notched" sample. The purpose of this notch is to concentrate the deformation to one localized part of the test piece. The shape and position of the notch have an important influence on the results and therefore have been more or less standardized.

The results given here were obtained on the Izod test in which the sample is tested as a cantilever beam with the notch at the point of greatest stress. The samples were 10 millimeters

square with the bottom of the notch on the center line of the test piece. The notch was 2 millimeters wide with a 1 millimeter radius at the bottom, machined by drilling and slotting.

The test piece is broken by a falling pendulum weight. The energy required to break the test piece is read in foot pounds from the scale. A series of tests to determine the effect of heat treatment on physical properties (50) of Armco ingot iron included some impact tests. The heat treatment is the same described under "Tensile Tests on Armco Ingot Iron Forgings." Table XIV gives the average of three tests on each bar.

These results show the bar which was finished cold has the

**Table XIV**
**Effect of Heat Treatment on the Impact Value of Armco Ingot Iron Forgings**

| Bar No. | Heat Treatment | Average Impact value-ft. lbs. per sq. in. |
|---|---|---|
| 1 | As forged, finished cold | 503 |
| 2 | As forged, finished hot | 422 |
| 3 | Finished hot, annealed 25 hrs. at 1650° F., slow cooled | 69.5 |
| 4 | Finished hot, air cooled from 1725° F. | 390 |
| 5 | Finished hot, water quench from 1725° F. | 452 |
| 6 | Finished hot, water quenched from 1725° F., reheat 1200° F. air cooled | 276 |
| 7 | Finished hot, annealed 2½ hrs. at 1650° F., fairly slow cooled (more rapid than No. 3) | 163 |

highest impact value while the one annealed 25 hours at 1650 degrees Fahr. and slow cooled had a very low impact value. Reference has already been made to the differences between these samples from the standpoint of tensile properties and microstructure. Bar No. 3 had a very coarse grain structure which no doubt accounts for the low impact value.

Some additional impact tests on Armco ingot iron are reported in Technologic Paper No. 289 of the Bureau of Standards (51). The specimens were 10 millimeters square and had four different styles of notches as follows:

**Standard**—A 60-degree V-shaped notch, 2 millimeters deep with a 0.25 millimeter radius in the bottom of the notch.
**Sharp**—A 60-degree V-shaped notch, 2 millimeters deep with a sharp 60-degree angle all the way to the bottom.

**Round**—A round bottomed notch, 2 millimeters wide, 2 millimeters deep with a 1 millimeter radius at the bottom.
**Deep**—A 5 millimeter deep straight sided notch with a 1 millimeter radius at the bottom.

The impact tests were made on an Izod pendulum type machine of 120 foot-pounds capacity. The results are given in foot-pounds, but these have been computed to a basis of foot-pounds per square inch cross section at the base of the notch in order to afford better comparison. Each value is stated to be the average of at least four tests.

**Table XV**
**Effect of Shape of Notch on Impact Value of Armco Ingot Iron**

| Type of Notch | Impact value in foot-pounds per square inch cross section at the base of the notch* |
|---|---|
| Standard | 430 |
| Sharp | 439 |
| Round | 495 |
| Deep | 369 |

*On these samples the notch was machined at right angles to the plane of rolling.

The "deep" notch is the one which is comparable to the tests on the heat treated bars previously described and it will be seen that the value of 369 foot-pounds per square inch of cross section in Table XV is of the same order as that already given on Bar No. 4 which was finished hot in forging and air cooled from 1725 degrees Fahr. In addition to these impact tests this paper (51) gives the results of some slow bending tests on notched bars, the tests being made on the Humfrey slow-bend machine. The reader is referred to the original work for the results of these tests and discussion thereof.

*Fatigue Tests*—The resistance of metals to repeated stresses is a problem which has engaged the attention of engineers for a great many years. Although it has been nearly 60 years since Wöhler published the results of his investigations on this subject it has only been within the last few years that notable progress has been made. A discussion of the various theories of fatigue failure is out of place in this paper. It will be sufficient to give the results that have been obtained in various fatigue tests on Armco ingot iron.

Many different ones have worked upon this subject, but Prof. H. F. Moore of the University of Illinois Engineering Experiment Station has perhaps conducted more tests on Armco ingot iron than any other investigator. These results are reported in various Bulletins of the University of Illinois Engineering Experiment Station (52). These should be consulted for details as to the methods of conducting the tests.

By way of explanation, however, it may be said that these results are given in terms of an "endurance limit" which is defined as that unit stress under which the material will endure 100,000,000 reversals without failure. It was found that, starting

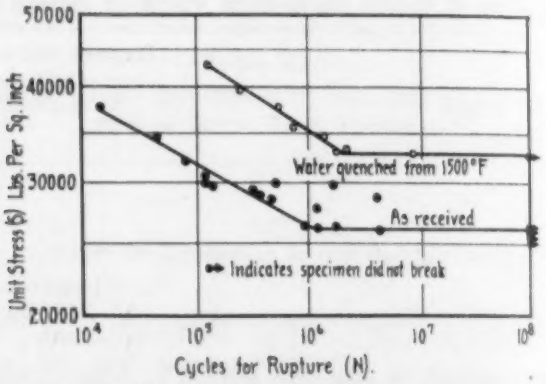


Fig. 28—Results of Fatigue Tests on Armco Ingot Iron as Received and Water Quenched from 1500 degrees Fahr. Reversed Bending Tests of Rotating Beam Machine (Farmer Type) Note: Curves plotted from test data reported by University of Illinois Engineering Experiment Station. Bulletins 124 and 142 "Investigation of the Fatigue of Metals."

from a high stress, the "life" increased as the stress was decreased. A large number of specimens of each material was tested, each one at a different stress, decreasing until no failure occurred after 100,000,000 reversals. When stress was plotted against number of reversals on log log coordinates, the "curve" was found to consist of two straight lines, one sloping down to the right and the other running horizontal at an ordinate equal to the "endurance limit" stress. Such a diagram for Armco ingot iron is shown in Fig. 28.

The various fatigue tests conducted by the University of Illinois Engineering Experiment Station included the following:

Rotating beam tests (Farmer type of machine); reversed bending tests (Upton-Lewis machine); reversed torsion tests

**Table XVI**

**"Static" and Impact Tests on Armco Ingot Iron Made by University of Illinois Engineering Experiment Station Preliminary to Fatigue Tests on the Same Lot of Material**

| Physical Property | "As Rec'd" | "Quenched" |
|---|---|---|
| **TENSION TESTS** | | |
| "Set" elastic limit | 14,400 #/in² | ..... #/in² |
| Proportional elastic limit | 16,100 | 35,000 |
| Yield Point | 19,000 | 36,300 |
| Ultimate strength | 42,400 | 50,000 |
| % Elongation in 2" | 48.3% | 36.3% |
| % Reduction of area | 76.2% | 76.0% |
| **COMPRESSION TESTS** | | |
| "Set" elastic limit | 19,400 #/in² | |
| Proportional elastic limit | 19,200 | |
| Yield Point | 20,600 | |
| Ultimate strength* | 31,200 | |
| **TORSION TESTS** | | |
| "Set" Elastic limit | 12,400 #/in² | |
| Proportional elastic limit | 12,500 | |
| Yield point | 13,600 | |
| Modulus of elasticity in torsion | 11,770,000 | |
| **MISCELLANEOUS TESTS** | | |
| Brinell hardness | 69 | 109 |
| Scleroscope | 18 | 20 |
| Impact bending (Charpy)—energy of rupture. 2mm round bottomed notch 5mm deep | 19.3 ft. lb. | 53.7 |
| Impact tension (Charpy)—energy of rupture ¼" round | 84.9 ft. lb. | |
| % Elongation in 2" | 27.0% | |
| % Reduction of area | 72.7% | |

*In a private communication to the author, Prof. Moore stated that these failures were by buckling or bending and although a very definite maximum reading was obtained he did not place a great deal of confidence in the results being an expression of the true ultimate strength in compression.

As a matter of fact a pure compression failure in a ductile material cannot be attained in practice as the specimen flattens and spreads, building up an increasing load as long as the test is continued or until the capacity of the testing machine is reached. A curve for such a test is shown in Fig. 32.

(Olsen-Foster machine and Illinois machine) reversed axial stress tests.

In making these tests the effect of various variables was studied. These included the following:

Effect of finish of surface; effect of shape of specimen (radius of fillet); effect of speed of stress reversal; effect of previous stresses just below the endurance limit; effect of quenching; effect of case carburizing and subsequent heat treatment.

The Armco ingot iron used in these tests was furnished in the form of normalized hot-rolled 1-inch round bars. The fatigue tests were preceded with very careful "static" tests which included, tension, compression, and hardness tests. Impact tests were also made.

Table XVI gives the results of the "static" and impact tests on the material "as received" and "water quenched from 1500 degrees Fahr."

Table XVII summarizes the endurance limits for Armco ingot iron as determined by the various fatigue tests. These are given on the material "as received" and "quenched from 1500 degrees Fahr.," the samples having the "standard" form and finish.

**Table XVII**
**"Endurance Limit" of Armco Ingot Iron as Determined by Various Fatigue Tests Conducted by the University of Illinois Engineering Experiment Station**

| Type of test | "As Rec'd" | "Quenched" |
|---|---|---|
| REVERSED BENDING TESTS | | |
| Farmer rotating beam machine | 26,000 #/in² | 33,000 #/in² |
| Rise of temperature short time test | 26,000 | |
| Upton-Lewis machine | 23,000 | |
| REVERSED TORSION | | |
| Olsen-Foster machine | 12,500 #/in² | |
| Illinois machine | 12,800 | |
| AXIAL STRESS (COMPRESSION-TENSION) | | |
| Axial testing machine | 17,000 #/in² | |

The effect of surface finish of the specimens is shown in Table XVIII. These tests were all made on the Farmer rotating beam machine. It will be seen that a low result is obtained unless the surface has a fairly high polish. This same effect was observed in the case of a 0.49 per cent carbon steel included in the same test.

**Table XVIII**
**Effect of Surface Finish on Endurance Limit of Armco Ingot Iron as Determined by the Farmer Rotating Beam Fatigue Test**

| Finish | Endurance Limit |
|---|---|
| Rough turned | 23,100 #/in² |
| Smooth turned | 23,500 |
| "Standard" finish, "00" emery cloth | 26,000 |

The variation due to this cause was about the same in proportion for the two materials.

In discussing the results of the fatigue tests attention is called to the fact that the endurance limit for Armco ingot iron is higher than the yield point. This is not the case with the other materials that were tested. A specimen of 0.93 per cent carbon steel (pearlitic) was the only material that even approximated this proportion between endurance limit and yield point. The fact that one of these materials is almost pure ferrite and the other almost pure pearlite is taken as an explanation of this high ratio. In other words, a uni-constituent material seems to show a high ratio between these two quantities. Even an eutectoid steel does not seem to come quite as near to being uni-constituent as Armco ingot iron, as its endurance limit is a little below its yield point while the reverse is true for Armco ingot iron.

These statements should not be construed to mean that Armco ingot iron has a greater fatigue strength or "endurance limit" than steel for this is not the case. It is true, however, that a member of a machine or other structure can be designed to be made of Armco ingot iron on the basis of the static yield point and yet it will be safe for repeated stresses. In the case of steel an extra factor of safety would have to be introduced to take care of the lower ratio between endurance limit and yield point for such material. In other words, Armco ingot iron is adequately suitable to resist vibrational and fatigue stresses wherever it has been properly designed to meet the static stresses.

In addition to the tests already described, an investigation was made of the effect of the radius of the fillet on the endurance limit. All other variables were kept constant.

These results (Table XIX) show the effect of a sudden change in section of a member under stress. A similar proportionate decrease in endurance limit was obtained on a 0.49 per cent carbon steel included in these tests.

**Table XIX**

**Effect of Radius of Fillet on Endurance Limit of Armco Ingot Iron**

| Type of Sample | Endurance Limit |
|---|---|
| Square shoulder | 13,700 #/in² |
| ¼" radius | 22,200 |
| Standard specimen, 9.85" radius | 26,000 |

The effect of the speed of reversal of stress was studied in connection with the tests on the Farmer rotating beam machine and these results are given in Table XX for Armco ingot iron.

**Table XX**
**Effect of Speed of Reversal of Stress on Eudurance Limit of Armco Ingot Iron**

| Speed of Reversal of Stress | Endurance Limit |
|---|---|
| 200 R. P. M. | 24,200 #/in² |
| 1500 | 26,000 " |
| 5000 | 26,300 |

The conclusion drawn from these tests is that although speed has some effect on the results, the variations are not large for any increase in speed above 1500 revolutions per minute and any slight variations during a test are not enough to affect the results. The standard speed used in all except these experiments was 1500 revolutions per minute.

The effect of stressing the material just below the original endurance limit seems to be to raise the endurance limit. A specimen of Armco ingot iron was stressed at 25,900 pounds per square inch for 100,409,100 cycles in the Farmer machine. The stress was then increased to 26,800 pounds per square inch, which is above the original endurance limit. After 55,230,100 cycles the specimen was unbroken and the stress was increased to 27,700 pounds per square inch after which it ran for 50,437,200 more cycles before failure. This indicates that under stresses near but below the endurance limit the resistance of the material to reversed stresses may be actually increased.

The only tests reported on the endurance limit of heat treated Armco ingot iron were on specimens water quenched from 1500 degrees Fahr. This treatment was found to raise the endurance limit from 26,000 to 33,000 pounds per square inch. It will be remembered that a similar heat treatment was found to improve the notched bar impact values reported under that heading in this paper.

In order to determine the effect of case carburizing, a number of specimens of Armco ingot iron were carburized in an electric furnace with a commercial carburizing compound. The samples were brought up and kept at a temperature of 1665-1675 degrees

Fahr. for periods of 3½, 2½ and 2 hours respectively. The resulting depths of case were 0.075, 0.025 and 0.015 inch respectively. Various heat treatments were carried out on these specimens and they were then tested in the regular Farmer rotating beam machine. The results are given in Table XXI.

**Table XXI**
**Endurance Limit of Case Carburized Samples of Armco Ingot Iron After Various Heat Treatments**

| | Heat Treatment | Depth of case In-ches | Depth of case % of diam | Endurance Limit #/in² | Increase over Armco Ingot Iron "as rec'd" |
|---|---|---|---|---|---|
| | As received | 0 | 0 | 26,000 | ... |
| F | Heat to 1600° F., hold 15 min., oil quench. Reheat 1450° F., hold 15 min., oil quench. Reheat 1200° F., hold 30 min., air cool | 0.015 | 5.0 | 37,000 | 42 |
| E | Heat 1600° F., hold 15 min., oil quench reheat 1450° F., hold 15 min., oil quench | 0.015 | 5.0 | 44,000 | 69 |
| H | After carburizing allow to cool in furnace | 0.025 | 8.3 | 27,000 | 4 |
| G | Heat 1450° F., hold 15 min., oil quench | 0.025 | 8.3 | 56,000 | 115 |
| E | (As above for E) | 0.025 | 8.3 | 57,000 | 120 |
| F | (As above for F) | 0.075 | 25.0 | 50,000 | 92 |
| E | (As above for E) | 0.075 | 25.0 | 68,000 | 162 |

*Machinability*—Armco ingot iron is soft and tougher than ordinary mild steel and therefore has slightly different machining qualities. Machinists who are familiar with Armco ingot iron find that it is advantageous to grind lathe and shaper tools with a little more "rake" when machining this material, otherwise the soft metal has a tendency to "drag". When this simple requirement is observed the material machines as well and as easily and will take just as smooth a finish as mild steel.

In order to determine the effect of heat treatment on the machinability of Armco ingot iron, a series of tests (54) was carried out on the same heat treated forgings previously described under "Tensile Strength of Forgings." The operations performed on these forgings were splitting in a shaper and turning and threading in a lathe. Neither the machinist nor the observer noticed any

unusual difficulty in any of these operations. Of the various heat treatments, Bar No. 5, which had been water quenched from 1725 degrees Fahr. machined and threaded somewhat better than the others. All of the bars, however, machined in a perfectly satisfactory manner.

*Flexure Tests on Corrugated Sheets*—In order to determine

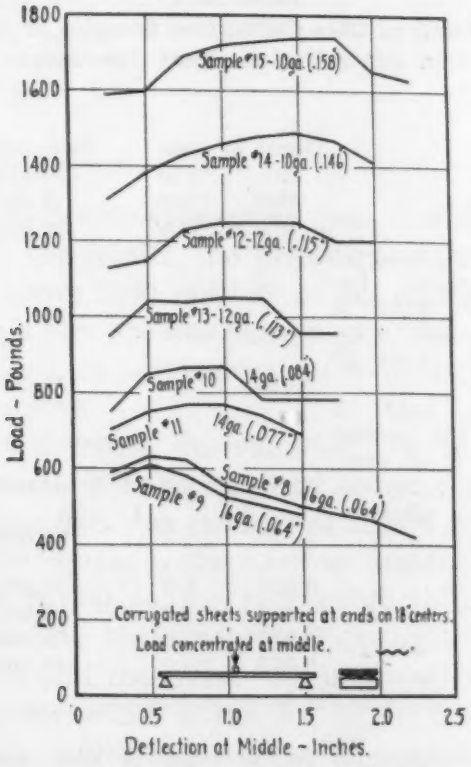


**Fig. 29—Results of Flexure Tests on Armco Ingot Iron Corrugated Sheets.**

the relative stiffness of corrugated sheets of different gages, a series of flexure tests (55) was carried out on 10, 12, 14 and 16 gage strips about 7 to 8 inches wide. The strips were supported at each end and loaded at the mid-point, the tests being performed in a 100,000 pound Riehle testing machine because this size of machine permitted a wider sample than a smaller machine which was available. Two sets of samples were tested, 18 inches on centers and two sets, 36 inches on centers.

The purpose of the tests was not to plot accurate stress-strain curves but to note the general character of such a curve and obtain the maximum load the sample would withstand. With this point

**Table XXII**

**Flexure Tests on Armco Ingot Iron Galvanized Corrugated Sheets**

| Samp. No. | Ga. | Span Inches | Thickness of Samp. Inches | Width of Samp. Inches | True Width of Samp. Inches | True Area of cross section sq. in. | Max load in pounds |
|---|---|---|---|---|---|---|---|
| 1 | 16 | 36 | 0.077 | 7.70 | 8.30 | 0.639 | 410 |
| 2 | 16 | 36 | 0.070 | 7.94 | 8.56 | 0.599 | 330 |
| 3 | 14 | 36 | 0.084 | 7.46 | 8.20 | 0.688 | 420 |
| 4 | 12 | 36 | 0.117 | 7.64 | 8.10 | 0.947 | 570 |
| 5 | 12 | 36 | 0.120 | 7.92 | 8.46 | 1.013 | 600 |
| 6 | 10 | 36 | 0.148 | 7.40 | 7.98 | 1.182 | 780 |
| 7 | 10 | 36 | 0.159 | 7.00 | 8.58 | 1.364 | 780 |
| 8 | 16 | 18 | 0.064 | 7.92 | 8.58 | 0.549 | 630 |
| 9 | 16 | 18 | 0.064 | 7.92 | 8.58 | 0.549 | 610 |
| 10 | 14 | 18 | 0.084 | 7.62 | 8.28 | 0.695 | 870 |
| 11 | 14 | 18 | 0.077 | 7.50 | 8.16 | 0.628 | 770 |
| 12 | 12 | 18 | 0.115 | 8.00 | 8.58 | 0.986 | 1250 |
| 13 | 12 | 18 | 0.113 | 7.60 | 8.10 | 0.915 | 1050 |
| 14 | 10 | 18 | 0.146 | 7.28 | 7.98 | 1.164 | 1490 |
| 15 | 10 | 18 | 0.158 | 7.00 | 7.58 | 1.198 | 1740 |

in mind, load readings were taken at ¼-inch intervals of deflections.

Each strip was three corrugations wide and was tested with the curved edges up. This gave four points of support at the center loading point and three at each end. The dimensions of the test pieces and the maximum loads are given in Table XXII. The value "true width" is the actual width of the sheet metal if flattened out. The individual load readings are not given but Figs. 29 and 30 show the results graphically. Fig. 29 is for the samples tested on 18-inch centers and Fig. 30 for those on 36-inch centers.

The results given in Table XXII may be summarized by averaging the maximum loads for each gage and span if the slight differences in thickness and width are neglected.

**Table XXIII**

**Average Results of Flexure Tests on Armco Ingot Iron Galvanized Corrugated Sheets**

| Gage | Nominal Thickness | Average maximum load 36″ Span | 18″ Span |
|---|---|---|---|
| 16 | 0.0625″ | 370 pounds | 620 pounds |
| 14 | 0.0781 | 420 | 820 |
| 12 | 0.1094 | 585 | 1150 |
| 10 | 0.1406 | 780 | 1615 |

Taking these figures as approximately correct it will be seen that the 18-inch span will stand about two times the load of the 36-inch span. This was to have been expected from the laws of mechanics. For a given length of span, the maximum load varies almost directly with the thickness of the sheet. This is contrary

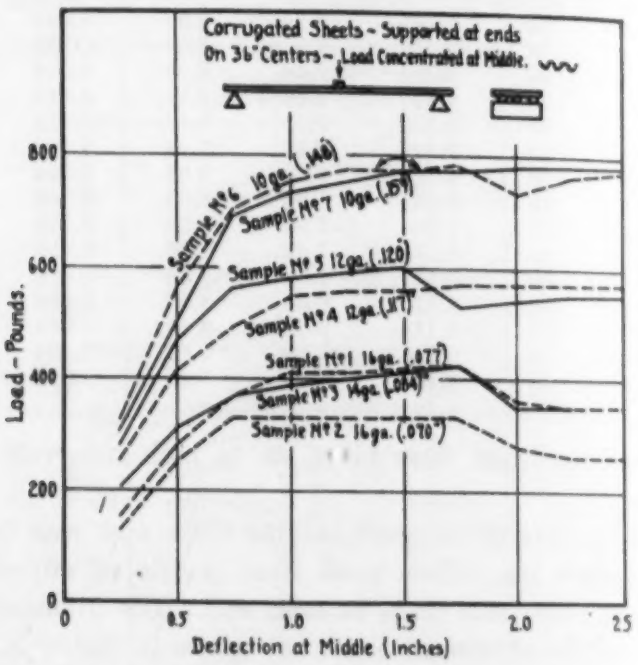


Fig. 30—Results of Flexure Tests on Armco Ingot Iron Corrugated Sheets.

to the law for rectangular beams which states that the strength varies as the square of the thickness.

The failure of a corrugated sheet tested in this manner comes through the buckling of the corrugations. In this respect it differs from a flat plate or rectangular beam. Most of this buckling seems to occur on the edge corrugations and for this reason a wider sheet should be stiffer in more than a direct proportion to the difference in width. However, the error would be on the side of safety to consider the stiffness of a wider sheet proportionate to the ratio of the widths. It does not follow, however, that a strip half as wide as those tested would be half as stiff.

While the ratio of direct proportionality between gage and maximum bending load seems to hold for the narrow strips tested, it is not certain that it would hold for wider sheets. It seems rea-

sonable that with wider sheets the stiffness would increase in more than a direct proportion to gage and come nearer to increasing as the square of the thickness as is true with flat plates and rectangular beams. However, the error is on the side of safety to assume direct proportionality between these two quantities.

*Shearing Strength*—Two methods are available for the determination of the ultimate shearing strength; one is the torsional test on hollow specimens and the other is the direct shear test carried out with suitable shear tackle in the universal testing ma-

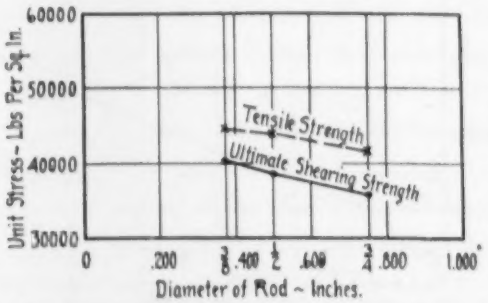


**Fig. 31—Curves Showing the Ultimate Shearing Strength and Tensile Strength of Hot Rolled Armco Ingot Iron Rods. Tested as Received.**

chine. The results given here (56) for Armco ingot iron were determined by the latter method, using a special shear block which tested the material in double shear. Special precautions were taken to eliminate or rather minimize the bending effect.

The movable shear block fitted snugly between the stationary blocks and was 1 inch thick, thus giving ample bearing surface for the portion of the rod between the two planes of shear. Extra screws were used to hold down the free ends of the rod and prevent bending as much as possible. The results of these tests are given in Table XXIV and shown graphically in Fig. 31. Each value in the table is the average of nine tests, three tests on each

**Table XXIV**

**Ultimate Shearing Strength of Hot-Rolled Armco Ingot Iron Rods Tested in the Condition "As Received"**

| Nominal Size | Ultimate Shearing Strength #/in² | Tensile Strength #/in² | Ratio of Shearing to Tensile Strength |
|---|---|---|---|
| 3/8" | 40,630 | 44,660 | 0.909 |
| 1/2 | 38,730 | 44,040 | 0.878 |
| 3/4 | 35,800 | 41,900 | 0.854 |

of three different random rods of hot-rolled Armco ingot iron purchased in the open market. The rods were tested in the condition "as received."

It will be seen from these results that there is a tendency for the larger rods to have a lower ultimate shearing strength. The tensile strength is given for the same rods for comparison and it will be seen that it follows the same trend. This effect is explained by the fact that in rolling the smaller sizes of rod it is

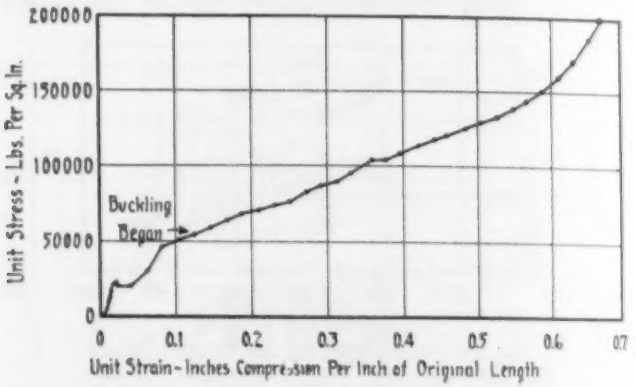


Fig. 32—Stress-Strain Curve Showing the Results of a Compression Test on Armco Ingot Iron Hot Rolled Rods. Test Sample No. 5515 Loaded up to the Capacity of 100,000 Pound Testing Machine. Original Dimensions of Sample 0.798 Inches Diameter, 2.380 Inches High.

necessary to make a larger number of passes through the rolls and as a result the finishing temperature is lower than on the larger sizes. This, together with the fact that the smaller sizes suffer greater reduction, explains this variation in physical properties in relation to the size of the rod.

Attention is called to the ratio between the ultimate strength in tension and shear. This ratio is usually given as 0.80 (57) (58) but in this case appears to be somewhat higher than this.

*Compression Tests*—In making a compression test or crushing test on ductile materials only the yield point can be determined as there is no such thing as "maximum strength" in compression for such materials. Johnson (59) says, "There is no such thing as an 'ultimate strength' in compression of a plastic body. There is, however, a definite 'apparent elastic limit,' the same as in tension. Beyond this limit the material simply spreads, and increases the area of its cross section indefinitely under an increasing load. [See Fig. 32 which shows a stress-strain curve for a

compression test on Armco ingot iron.] The elastic limit in compression of such a material is the greatest load from which the specimen will fully recover, or it is the greatest load within which the stress and deformation bear a constant ratio to each other. This elastic limit in compression for wrought iron and steel is, fortunately, about the same in pounds per square inch as the elastic limit in tension. It is not customary, therefore, to test such materials in compression, but to assume that they have the same elastic limit in compression which they are found to have in tension."

In connection with an investigation on the fatigue of metals, the Engineering Experiment Station of the University of Illinois reports (60) the results of some compression tests on Armco ingot iron. The tests were made on the material in the condition "as received" which was normalized hot-rolled 1-inch round bars. The results reported are quoted in Table XXV.

**Table XXV**
**Compression Strength of Armco Ingot Iron**

| Property | Value in lbs. per sq. in. |
|---|---|
| "Set" elastic limit in compression | 19,400 |
| Proportional elastic limit | 19,200 |
| Yield point | 20,600 |
| Ultimate strength | 31,200[1] |

[1]The fact that an ultimate was obtained suggests that a long specimen was used and failure was by bending rather than true compression. This supposition is confirmed by a private communication from the University of Illinois Experiment Station. The result obtained was the maximum load the test piece withstood before buckling but this cannot be taken as a true value for the ultimate strength in compression as the failure was not a compression failure.

*Modulus of Elasticity*—The modulus of elasticity is one of the fundamental conceptions of mechanics upon which most formulae for the strength of materials depend. It is the ratio of unit stress to unit deformation within the proportional limit of the material and is assumed generally to be the same in tension and compression. The statement is frequently made that the modulus of elasticity is the same for all ferrous materials regardless of heat treatment and is approximately 30,000,000.

The modulus of elasticity may be easily determined from the stress-strain curve by determining the slope of the curve below the proportional limit. It can be found by means of a flexure test by solving the beam formula for E, the other quantities all being known. If either of these methods are used in making actual

tests it will be found that there is actually a considerable variation in the modulus as determined on different samples. This is due to the experimental error which may be rather high in tests of this sort.

The modulus of elasticity of Armco ingot iron has been determined on a number of different kinds of samples with the results given in Table XXVI (78).

**Table XXVI**

**Modulus of Elasticity of Armco Ingot Iron**

| Kind of sample and method of testing | E |
|---|---|
| Tension test on 16-gage Blue annealed sheet | 31,380,000 |
| Tension test on 24-gage Blue annealed sheet | 29,800,000 |
| Tension test on 1/4″ Blue annealed plate | 26,500,000 |
| Tension test on 14-gage Blue annealed sheet | 30,250,000 |
| Flexure test on 5/8″ round cold-rolled rod 12 inches on centers and loaded at mid-point | 29,100,000 |
| Flexure test on 5/32″ round cold-rolled rod 2.75 inches on centers and loaded at mid-point | 28,600,000 |
| Flexure test on 8, 10, 12 and 14-gage sheets of galvanized Armco ingot iron 8″ wide and 12″ on centers and loaded at mid-point | 29,249,000* |

*Average of duplicate tests of the various gages named.

In the case of the tensile test the modulus can be determined more accurately than in the ordinary flexure test if an accurate extensometer is available. The values of E in Table XXVI determined on tension tests were made with an Olsen extensometer which reads directly elongations of 0.0001 inch on a 2-inch gage length. By means of a magnifying glass accurate dial readings were made to one-tenth of a division on the scale, or 0.00001 inch. This is equivalent to an elongation of 0.000005 inch on a one inch gage length. In making these tests a pointer was fastened to the end of the beam so that it could always be balanced at the same position in the trig loop of the testing machine.

If only the values from the tensile tests are considered the average for E is 29,480,000. But the values obtained from the flexure tests cannot be ignored, especially the one for tests on galvanized sheets of various gages, for this is an average of a considerable number of tests. An average of all the values in Table XXVI gives 29,270,000. This may be taken as an average value of E for Armco ingot iron.

*Modulus of Resilience.* The resilience of a material is a measure of the energy that can be stored up in it when it is put under stress. We usually think of a spring as being resilient because it will give up a certain amount of energy when the force that keeps it strained is released. All materials have a certain amount of resilience and for purposes of comparison we speak of the "modulus of resilience" which is the amount of energy that can be stored up and recovered from one unit volume of the material. In ordinary units it is equivalent to the number of inch-pounds of energy per cubic inch of the material.

This quantity is really the area under the stress-strain curve up to the elastic limit and as the elastic limit of a given material varies with the treatment, so the modulus of resilience will depend on the working and heat treatment of the piece in question.

As a matter of fact, by engineering convention, the yield point is used instead of the elastic limit in making a computation of the modulus of resilience of ductile materials (76). The modulus of elasticity will be assumed at 29,250,000. As has been shown under the various headings in this paper, the yield point of Armco ingot iron varies between 18,300 for a dead soft annealed forging to 59,300 pounds per square inch for cold-rolled rods. The modulus of resilience will then vary between 5.73 inch-pounds per cubic inch for the dead soft annealed condition to 60.3 inch-pounds per cubic inch for the cold drawn material, the yield points being assumed as above.

While resilience really implies the power of restitution, the term is sometimes used to mean the total work done up to fracture. This leads to some ambiguity as the total work up to fracture is quite a different value and depends on the ductility as well as the strength while the modulus of resilience as given above depends on the elastic limit and modulus of elasticity. A ductile material of lower elastic limit may require more work to rupture than another of higher elastic limit but lower ductility.

*Stress-Strain Diagrams.* Stress-strain diagrams for a given material may show tensile, compression, shearing or torsional stresses plotted against the corresponding strains. It is customary to construct these diagrams on the basis of unit stresses and unit strains in order that the different diagrams may be compared.

The stress-strain diagrams given here for Armco ingot iron

are all from tension tests with the exception of one which is for a compression test. Fig. 33 is for cold-rolled round rod machined from ⅜ to ¼ inch diameter over a gage length of two inches. The parallel section was actually 2¼ inches long. An Olsen extensometer, the accuracy of which has been described,

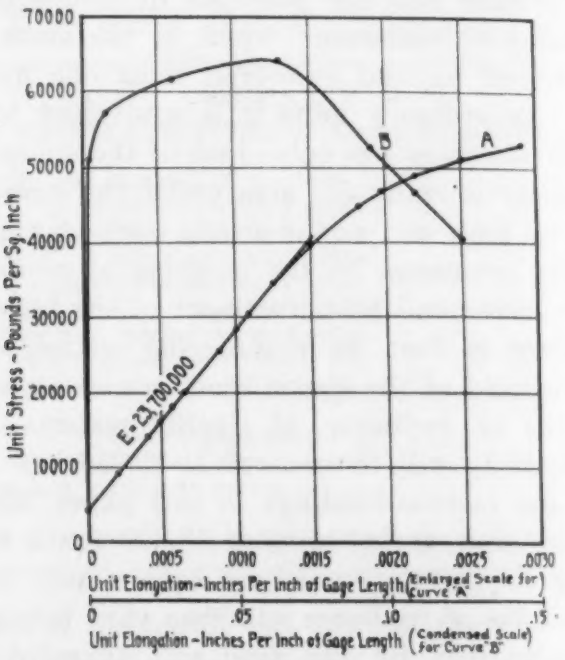


Fig. 33 — Stress-Strain Curve for Cold-Rolled Armco Ingot Iron Round Rod Machined to ¼ Inch From ⅜ Inch with 2-Inch Gage Lengths.

was used in all of these tests. This cold-rolled material shows a low value for the modulus and an indefinite elastic limit. The former is frequently and the latter nearly always observed for material that has had any considerable amount of cold working.

Fig. 34 shows a stress-strain diagram for ¼ inch blue annealed Armco ingot iron plate. The test was made on an 8-inch gage length but the readings below the yield point were taken over a 2-inch gage length with the Olsen extensometer. Elongations above the yield point were taken over the full eight inches by means of dividers and scale. After the maximum load was reached the weight was backed up to read the load corresponding to the elongation reading. The lower part of the stress-strain curve for 16-gage blue annealed Armco ingot iron is shown in Fig. 35. This was made on a 2-inch gage length specimen

using an Olsen extensometer for reading the elongations. These curves are given as typical for several different samples of Armco ingot iron. Different treatments that the material may be subjected to result in different properties and these in turn affect the shape of the stress-strain curve. Attention is called to the

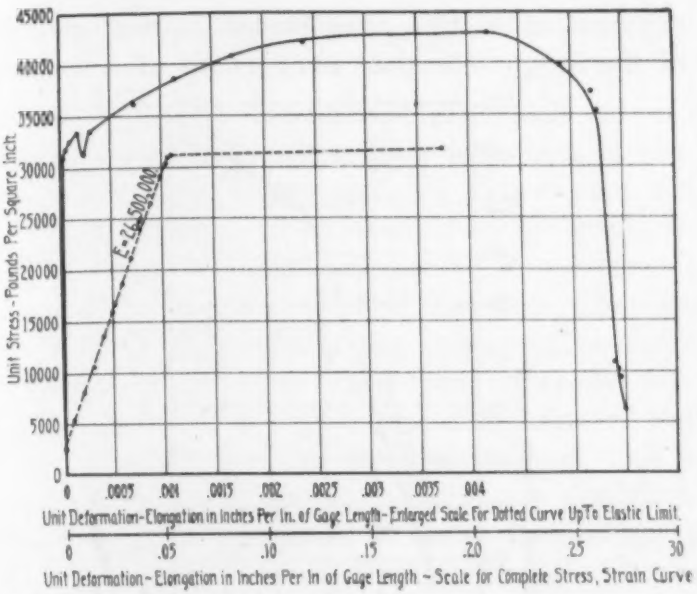


Fig. 34—Stress-Strain Curve for Armco Ingot Iron ¼ Inch Blue Annealed Plate in Tension Test.

difference between the curve for cold-rolled rod and blue annealed plate.

*Critical Working Range.* Armco ingot iron differs from the mild steels in many ways, but one of the most striking differences is probably the "critical working range", which is one of the peculiar properties of Armco ingot iron. Anyone who has tried to forge or hot work this material has found that there is a certain range of temperature in which Armco ingot iron is not malleable. A demonstration can be easily made by heating one end of a small section, say ½x½ inch, to about 2000 or 2100 degrees Fahr. As the piece cools bend the hot end back and forth by hammering over the edge of a blacksmith's anvil. A square section is better than a round one as it will not turn as easily and so can be held more firmly for bending. This bending back and forth should be kept up continuously as the piece cools. When the temperature drops to about 1900 to 1950 degrees Fahr.

the metal will seem to be quite brittle and will break off without bending. If a new bend is started immediately an inch or so back from this break and the working continued it will be found that the brittle condition persists until the temperature drops to about 1650 degrees Fahr. Below this point the material is again perfectly ductile and malleable.

An explanation of this phenomenon is now in order. It is a result of the unique chemical composition of Armco ingot iron.

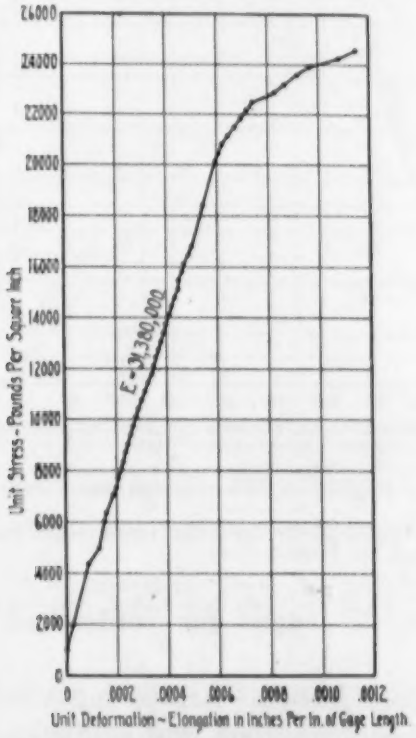


Fig. 35—Stress-Strain Curve for Armco Ingot Iron 16 Gage Blue Annealed Sheet in Tension Test.

The detailed analysis has already been discussed in detail and it is the intention here to merely call attention to the low manganese content as compared with mild steel. It is well known that manganese and sulphur have a great affinity at high temperatures and form manganese sulphide, MnS. From the atomic weights it will be seen that 55 parts of manganese by weight are required to combine with every 32 parts of sulphur by weight. In other words, a steel containing 0.032 per cent sulphur would have to have at least 0.055 per cent manganese in order that all the sulphur would be in the form of MnS. As a matter of fact,

an excess of manganese is required to overcome the mass action of the iron which otherwise tends to form FeS. In any case a deficiency of manganese results in the formation of FeS. In the case of Armco ingot iron there is a decided deficiency of manganese to satisfy the reaction

$$Mn + S \rightarrow MnS$$

What sulphur is present is therefore practically all in the form of FeS. This forms an eutectic alloy with iron of the approximate composition FeS 85 per cent, Fe 15 per cent (61). This eutectic shows a tendency to be rejected to the grain boundaries. In the case of excessively high sulphur (0.54 per cent) in special samples, a definite network of FeS has been identified in the grain boundaries. While this is not prominent enough to be detected in Armco ingot iron, which has relatively low sulphur, it is doubtless true that a "sub-microscopic" film of FeS is present. Sauveur reports that the melting point of this eutectic is 1742 degrees Fahr. (950 degrees Cent.). It doubtless loses its strength at temperatures somewhat below its melting point, for the lower limit of the "critical working range" of Armco ingot iron is about 1650 degrees Fahr. Between 1650 and about 1950 degrees Fahr. the presence of this molten or at least plastic Fe-FeS eutectic in the grain boundaries makes the material non-workable.

When the temperature is raised to about 1950 degrees Fahr. the brittle condition gradually disappears as the temperature increases. One explanation of this is that it may be due to the diffusion of the FeS or Fe-FeS eutectic throughout the entire structure at the higher temperatures. This diffusion would distribute this weak constituent throughout the mass and remove it from the grain boundaries, thus restoring the ductility. If this reaction takes place it is reversible, for the brittleness returns on cooling to the proper temperature.

Another explanation that has been given is that changes in the surface tension of the FeS or Fe-FeS eutectic occur at the higher temperatures causing it to "ball-up". The plastic metal thus re-unites breaking down the previously existing films that occurred in the grain boundaries. When the metal again cools below a certain temperature the iron sulphide is rejected to the

grain boundaries and until it solidifies at a still lower temperature the metal is brittle and non-workable.

From the above discussion it will be seen that, from the theoretical standpoint, the ratio of sulphur to manganese determines the presence or absence of the "critical working range" This has been verified by experiments on the forgeability of special samples of Armco ingot iron with sulphur as low as 0.010 per cent. These samples had no "critical working range". At the present time it is impossible to produce Armco ingot iron of this low sulphur content in commercial quantities although it is the constant aim of the manufacturers to reduce this impurity to a minimum. In the ordinary ranges of sulphur and manganese in normal Armco ingot iron, the variation which occurs in these elements has very little effect on the "critical working range". This is probably due to the fact that the elimination of this condition requires that the sulphur be theoretically not over half and in practice not over one-third the manganese. Ordinarily it is higher than the manganese.

A series of "critical" forging tests on some specially prepared samples of Armco ingot iron with a variation in sulphur content of 0.041 to 0.094 per cent, obtained by addition of sulphur, caused only a slight widening of the "critical working range". On the 0.041 per cent sulphur material it was 1634-1922 degrees Fahr. (890-1050 degrees Cent.), while on the 0.094 material it was 1616-1976 degrees Fahr. (880-1080 degrees Cent.). Armco ingot iron never has a sulphur content as high as the highest of these specially prepared samples.

*Thermal Critical Points.* The preceding discussion on "critical working range" must not be confused with "thermal critical points". The former is due to the changes in physical form and occurrence of certain impurities (sulphur and manganese), while the latter are evidence of allotropic changes in the metal itself.

In the case of pure iron the $A_1$ point is absent due to there being no carbon present. The determination of the $Ar_3$ and $Ac_3$ as well as $Ar_2$ and $Ac_2$ points has been made by many different investigators. Dr. Sauveur (62) considers the results of Dr. G. K. Burgess and J. J. Crowe to be the best available. Their values for these points are as follows: $Ac_3$—909 degrees Cent.; $Ar_3$—898 degrees Cent.; $Ac_2$ and $Ar_2$ both at 768 degrees Cent. These

values are for specially prepared samples of iron of high chemical purity but may be considered applicable to Armco ingot iron as the last traces of impurities such as are present in Armco ingot iron exert very little if any effect on the location of these transformation points.

*Resistance to Oxidation at High Temperature.* In order to determine the resistance of Armco ingot iron to oxidation or scaling at high temperature, a test (63) was conducted over a period of more than two years. A half inch thick plate of Armco ingot iron was fastened in a vertical position on a heavy base and placed in the stack of a coal-fired sheet annealing furnace where the exit gases were at a temperature of 1400 to 1650 degrees Fahr. It was exposed to the smoke and furnace gases. For purposes of comparison a mild steel plate of similar dimensions was mounted on the same base so that it would be subjected to identical conditions.

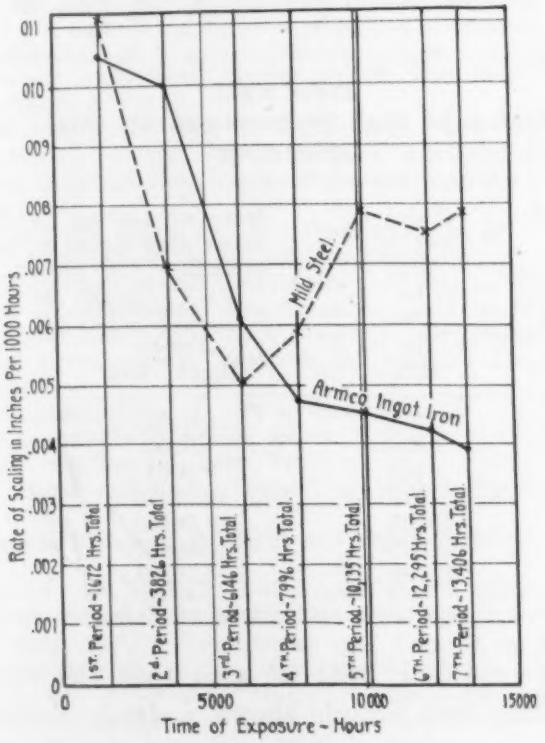


Fig. 36—Comparison of the Resistance to Corrosion at High Temperature of Armco Ingot Iron and Mild Steel.

The plates were removed about every three months for ex-

amination. The thickness of the plate under the scale was taken as a measure of the resistance to oxidation under these conditions. The loss in thickness from the original measurements was divided by the number of hours of exposure under heat and the result was called "rate of scaling per 1000 hours". This time is only the actual hours under heat and does not include any time the furnace was down for any reason. The actual results are given in Table XXVII and shown graphically in Fig. 36.

**Table XVII**

**Resistance to Oxidation at High Temperatures of Armco Ingot Iron and Mild Steel**

| Period No. | Length of Period Hrs. | Total Time of Test to Date in Hrs. | Rate of scaling in inches per 1000 hours over entire duration of the test including the period for which the result is given. | |
|---|---|---|---|---|
| | | | Armco Ingot Iron | Mild Steel |
| 1 | 1672 | 1672 | 0.0105 | 0.0111 |
| 2 | 2154 | 3826 | 0.0099 | 0.00693 |
| 3 | 2320 | 6146 | 0.0061 | 0.00504 |
| 4 | 1850 | 7996 | 0.00472 | 0.00584 |
| 5 | 2139 | 10135 | 0.00453 | 0.00790 |
| 6 | 2160 | 12295 | 0.00427 | 0.00753 |
| 7 | 1111 | 13406 | 0.00391 | 0.00787 |

From these results it will be seen that the rate of scaling of the Armco ingot iron sample shows a steady decrease with increase of time, whereas no such regularity is noticed in the case of the mild steel. An examination of the samples indicated an explanation for this. The scale on the mild steel was quite loose and easily flaked off while that on the Armco ingot iron was so tightly adherent that it could hardly be removed with a hammer and chisel. In the case of the Armco ingot iron, then, it would seem that this tightly adherent scale acts as a protective coating and so causes the rate of scaling to decrease as the scale becomes thicker and more protective.

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## DISCUSSION

**Written Discussion:** By Albert Sauveur, Harvard University, Cambridge, Mass.

We should be greatly indebted to the author for having placed before us in so satisfactory a manner an amount of information which up to date had been widely scattered and for his description and discussion of the properties of Armco ingot iron.

The author's contention on the sixth page that in Armco iron the dendrites formed on solidification may still exist at room temperature would imply the existence of dendrites made up of many micro-grains each micro-grain with its own crystalline orientation. Bearing in mind that a dendrite is a crystallite or allotriomorphic crystal and therefore of uniform crystalline orientation, it is evident that it cannot be made up of many crystalline grains of varying orientations. The granulation of a dendrite implies its obliteration as a crystalline unit. The dendritic segregation accompanying the formation of dendrites, however, persists which makes the revelation of dendritic patterns possible, although the dendrites themselves no longer exist. The fact that in Armco iron these dendritic patterns are not obtained must be ascribed to the great purity of this metal, hence nearly complete absence of dendritic segregation. This in turn results in nearly complete absence of "directional properties," the latter being due to the "banded" structure produced by hot work and resulting from the existence of dendritic segregation.

Referring to the critical working range the author adopts the classic view that red shortness is caused by the presence of FeS forming readily fusible films around the grains of iron. Having myself accepted that view in my writings, I should be the last one to criticise. May we not, however, question the validity of certain contentions in spite of the venerability conferred upon them by long acceptance, when we find that their applications do not satisfy existing conditions?

Let us consider Armco iron containing 0.03 per cent sulphur and 0.01 per cent manganese. It will have a critical working range extending from some 900 to 1000 degrees Cent. Simple calculations will show that the combinations believed to take place between sulphur, manganese, and iron will result in the formation of 0.016 per cent MnS and 0.066 per cent FeS. If we accept the claims that a Fe-FeS eutectic is formed 0.078 per cent of it will be produced. We are asked to believe that that extremely small proportion of FeS or of Fe-FeS eutectic, so small that it cannot be detected under the microscope, surrounds the ferrite grains and causes red shortness. Are we not justified in hesitating to accept it as the real explanation or must we accept it for lack of a more satisfactory one?

Let us note that as soon as iron passes from its gamma to its alpha condition it looses its red shortness. This must have some significance, and we may reasonably believe that alpha iron is never red short. We are concerned, therefore, with the red shortness of gamma iron between 900 degrees Cent, the lowest temperature at which it can exist and some 1000 degrees Cent. There are reasons for suspecting that red shortness is maximum at about 900 degrees Cent. and gradually decreases with increasing temperature to finally disappear at about 1000 degrees Cent.

In some twisting tests reported in my Howe lecture (American Institute of Mining and Metallurgical Engineers, May, 1924) I brought to light the fact that on heating bars of Armco iron at the center to different temperatures and hence resulting in temperature gradients and then twisting them, they twisted not as would reasonably be expected, at the hottest portion, but in the immediately vicinity of the $A_3$ point when the temperature was 900 degrees

Cent. ±. Similar results were obtained in twisting bars of electrolytic iron, wrought iron and mild steel. This must mean either that iron is more plastic while undergoing its allotropic transformation or that the portion which twisted corresponded to alpha iron at the highest temperature it can exist (900 degrees Cent.). I am now inclined to believe the latter view to be the more likely. When the centers of the bars were heated to temperatures in excess of some 1000 degrees Cent. the twisting occurred at the centers. We may infer from these tests (1) that gamma iron at the lowest temperature it can exist is less plastic than alpha at the highest temperature at which it can exist, this being for both allotropic varieties in the vicinity of 900 degrees Cent., (2) that the plasticity of gamma iron increases with its temperature, (3) that so long as the temperature of gamma iron remains inferior to 1000 degrees Cent. its plasticity is less than the plasticity of alpha iron at 900 degrees Cent., and (4) that at temperatures in excess of 1000 degrees Cent. the plasticity of gamma iron becomes greater than the plasticity of alpha iron at 900 degrees Cent. Assuming that this relative lack of plasticity of gamma iron between 900 and 1000 degrees Cent. is the cause of its red shortness, I am well aware that I am not supplying any explanation of the facts stated by the author (1) that iron practically free from sulphur is not red short, and (2) that if the manganese content amounts to three times the percentage of sulphur or more the metal is not red short. In spite of this failure on my part it has seemed worth while to call attention to a phenomenon which it seems to me must play a part in the red shortness of iron.

**Written Discussion:** By J. R. Cain, U. S. Bureau of Standards, Washington, D. C.

The typical analysis of Armco ingot iron given by Mr. Kenyon shows this metal to be the purest form of iron made by melting and refining methods in commercial quantities and shapes. The degree of purity attained seems to represent nearly the practical attainable limit for iron produced in large tonnages. Mr. Kenyon in his paper has made some comparisons with electrolytic iron. This material has been produced in amounts up to 25 tons per day somewhat purer than ingot iron. The sulphur in electrolytic iron that has not been melted will be 0.01 per cent or lower and manganese is present only in traces; the other impurities are about like Armco ingot iron. Thus, electrolytic iron may contain 0.02 to 0.03 per cent less of total impurity than Armco ingot iron does. However, this refers to electrolytic iron that has not been melted and this is an important limitation. As stated, the largest daily production of such electrolytic iron thus far reported is 25 tons per day, mainly as tubes. If it were desired to produce all commercial forms needed by the trade from electrolytic iron it would be necessary to melt it. If this melting were done in a basic open-hearth furnace it seems probable that the finished product would be no purer than Armco ingot iron on account of sulphur, silicon and carbon contamination during melting. Also, the melting losses would be very high unless very thick pieces of electrolytic iron were used for remelting, and such thick sections are not being commercially produced as far as known. If the melting is done in a commercial size (i. e., one-tone or over) arc furnace with basic or acid lining the pick-up of carbon, silicon, sulphur and phosphorus

makes the total content of these impurities in the melt much greater than in Armco ingot iron.

How difficult it is to melt electrolytic iron without contamination, even when laboratory furnaces and specially purified refractories are used, is shown by analyses of such melts given in Bureau of Standards Scientific Paper 266, of which the writer was co-author, and in a subsequent paper by Jordan et al (*Proceedings*, American Electrochemical Society, October, 1916, meeting, Advance Copy No. 8). In the first-mentioned paper the increase in impurity (i. e., sum of C, Mn, Si, P and S) of the melts ranges from 0.015 to 0.029 per cent. In the paper by Jordan and co-authors there was an increase of a few thousandths per cent total impurity when the melts were made in refractories purified or made by laboratory or other expensive methods. Using commercial, electrically sintered magnesia (itself a costly material) the pick-up varied from 0.005 to 0.013 per cent. With zirconia refractories the pick-up varied from 0.009 per cent to 0.240 per cent. The furnace used by Jordan and associates for these experiments was a vacuum electric furnace, so there was no chance for contamination of the melt by furnace atmosphere as always happens in commercial melting operations.

It seems probable that iron purer than ingot iron cannot be made commercially by remelting electrolytic iron. Advances in the art of electrodeposition may conceivably produce pure electrolytic iron in a variety of commercial shapes without the necessity of melting operations, but these shapes are not on the market today.

**Written Discussion:** By H. L. Whittemore, U. S. Bureau of Standards, Washington, D. C.

A knowledge of the fundamental properties of any material is the basis for the intelligent and efficient use. This fact is realized by the more advanced manufacturers, particularly the makers of Armco ingot iron. This material approaching as it does chemically pure iron has received an unusual amount of attention from scientific research laboratories both here and abroad which have little interest in its commercial development.

The data in this paper are unusually well presented and the references to the original publications are particularly valuable.

Of course, the use by materials engineers of the information in a paper of this kind, written by a member of the staff of the organization marketing the material, must depend upon their confidence in the organization and the reputation of the members of the staff. The original publications to which reference is made can, of course, be used if desired, but there is no way in which the omission of data which is unfavorable to the material can be determined unless the reader has access to a reasonably complete bibliography on the material. This paper by Mr. Kenyon is evidently a conscientious compilation of all the available information on this widely used material.

The discussion of the properties of Armco, as for example its compressive strength, shows an appreciation of the limitations of materials testing methods, which are too often overlooked.

The data sheets distributed by such organizations as the International Nickel Company and the Alleghany Steel Company show the recent trend

toward furnishing fundamental information on the properties of materials.

The Bureau of Standards has considered the compilation of existing data on materials an important service to consumers. Circulars revised from time to time have been issued on copper, zinc, nickel, aluminum, steel and other materials.

Circular 101, Physical Properties of Materials—metals and wood—covers, perhaps, the widest field. The lack of reliable data on many materials is strikingly shown by the unfilled portions of Table I, in this Circular.

Remembering that only the most important properties are listed in this table, which might be required by any user of a material, it is astonishing that values for less than half the properties are available.

It seems self-evident that our industrial development is greatly hampered by this lack of information on the properties of materials in extensive use; therefore Mr. Kenyon's paper should be welcomed by materials engineers as it adds considerably to our knowledge of the material upon which he has been working.

C. H. HERTY, JR.: I would like to bring out one point that I think is a little misleading in this paper. On the third page the percentage of carbon, manganese, phosphorus, sulphur and silicon sums up to .059, and the iron by difference is 99.941. I think that 99.941 must be considerably misleading, because when an ingot iron heat goes out of the furnace, it must be pretty well saturated with oxygen. It is very difficult to remove all that oxygen and the products of deoxidation, so this 99.941 is probably high.

Furthermore, according to the carbon-oxygen relationship, the lowest carbon content that you can get is not necessarily going to give the highest iron content, because the lower the carbon the higher the oxygen. There is some point on the carbon-oxygen curve, and it is not at 0.01 per cent carbon, which will give the maximum purity insofar as these different elements that Mr. Kenyon lists and oxygen are concerned.

PROF. H. F. MOORE: I would like to add, not at all a criticism, but a footnote to the results shown for the fatigue tests of Armco iron. The speaker stated that the endurance limit was found to be above the yield point. I think a little more accurate way of stating that would be to say that the computed stress at the endurance limit was above the yield point as determined by a tensile test. In a bending test of the computed stresses above the yield point it is, of course, greater than the real stress. Probably it would be safe to say that in the fatigue tests of Armco iron the endurance limit was found to be at least as high as the yield point. That does not at all invalidate the author's conclusions. From some fatigue tests of Armco iron made at the University of Illinois, it would seem that the yield point would be the governing strength factor in all cases, even for reversed flexure.

I might add that if it is necessary to consider endurance limit under reversals of shearing stress, as, for example, in a shaft under reversed torsion, the endurance limit will drop to about 55 per cent of the value under reversed bending.

N. A. KURMAN: I would like to attack this problem from a different angle. I felt somewhat out of place listening to the discussions of your steel

manufactures, and want to state that I became a steel treater but a short while ago. I am in the radio business, manufacturing loud speakers and the steels that we use are at both ends of the scale. For instance, physically and magnetically the permanent magnets are diametrically opposite to the armature. Only recently have we been able to obtain decent magnetic steel commercially, that by proper and careful heat treatment will respond in fair fidelity to all frequencies within the musical range, and I am sure, that if we had to revert to the irons and steels of a few years ago, reception would again be what it was when radio started. By this I want to emphasize that recent loud speaker improvement is due to nothing else but the virtue of the properties of the steel in the speech-magnetic circuit.

I am sorry Mr. Kenyon did not get as far as discussing magnetic properties. We have only recently come to depend upon steel of uniform quality for so complex an assembly as that of loud speakers, that give decent quality and decent speech. I wish to make the point that the whole art of radio reception and voice reproduction has advanced with, and depends upon, the quality of the steel used, and the particular heat treatment of each particular steel.

Even before I became a member of this society, I felt that I was a pretty good steel treater. I treated most of the stuff I received with a whole lot of contempt. (Laughter.) We had to develop sensitive and rugged methods of testing steels, after working, for their properties and thermal history. And we then obtained good speakers by throwing away 50 per cent of the material that passed through this test.

Keep in mind the fact that radio depends upon and advances with the properties of the steel. It has been proven that the best steel from a speech point of view is one that is practically carbonless. Commercially I have been able to do more with Armco iron-silicon alloy than with any other. I am not metallurgist enough to know just why, but the fact remains, we have determined empirically that we can obtain the properties we desire, by a somewhat complex heat treatment. I owe a debt to the Steel Treaters, to the work and research that you have done and freely given.

W. S. BUTTLES: There was a research conducted some time ago at the University of Illinois which showed that if the carbon content was over 0.005 per cent it made little difference from there on up to about 0.020 per cent Unless the carbon can be run below that range the hysteresis and eddy current losses will show little change.

Some other factors enter into the electrical properties of iron such as, the grain size, and general structure that affect the reversal of polarity and the losses. The hysteresis and eddy current losses in iron are difficult to separate from each other, while the hysteresis losses are caused by the impurities and the grain size, the eddy current losses, caused by electric currents being induced at right angles to the flux path, are a function of the resistivity of the path; so there are other things than the carbon content to consider in dealing with the magnetic properties of iron.

R. E. RUDER: There are two points on which I would like to raise a question with the author of this paper. One of them is that practically all of the photomicrographs of Armco iron that I have seen published have been

remarkably free of inclusions, while unfortunately, all of those that I have made myself—and I have made a good many—have shown quite a lot of oxide inclusions. I would like to know whether that is a general experience or whether I have just happened to get hold of poor Armco iron.

The other point, which has been brought up by the two previous speakers in discussing the paper, is that of the magnetic properties. It was brought out in the paper that Armco iron is very desirable because of its good magnetic properties. My experience has been exactly the opposite. The use in magnetic circuits to which Armco iron might be put, that is places where core loss is not involved and the requirement is merely one of high permeability, Armco iron is one of the poorest materials that can be used, because of its very high aging.

Freshly annealed Armco iron, it is true, has a high magnetic permeability, but if allowed to stand around at room temperature or if given the standard aging test at elevated temperature it will be found to have decreased in permeability something like fifty per cent. A manufacturer of electrical apparatus might easily be misled by such a change, for if he tested his material in the freshly annealed condition it might be entirely satisfactory, but after it was built into his apparatus and used, this aging might cause enough change to make that apparatus most unsatisfactory.

Now, if I am mistaken in my conclusions, drawn from a large number of tests on Armco iron, I would be glad to be corrected. This all goes back to another point which I think the first man discussing the paper brought out, and that is the high oxygen content of Armco. We have by experiment definitely connected the presence of oxygen with high aging, and the oxide dissolved in the metal, I believe is the cause for the high aging in Armco iron. Armco iron may be corrected of this aging by proper annealing in hydrogen for a long time, will remove this oxygen and make it an excellent magnetic material, but Armco iron as it is ordinarily sold, and with an ordinary anneal, will not give good magnetic results.

### Author's Reply to Discussion

Professor Sauveur comments regarding the statement on page 6 that "the positive assertion cannot be made, however, that the dendrites may not still exist, although they cannot be identified by any known etching method," and what he says indicates that I have doubtless erred in my use of the word, "dendrites". The correct use of the word should, undoubtedly, be limited to a description of the crystal form resulting from solidification. However, the structure due to dendritic segregation and revealed by certain etching reagents is generally spoken of as "dendritic" and the features of the etched pattern as "dendrities".

I wished to emphasize the absence of this "dendritic" structure in Armco ingot iron and have ascribed it to the high purity and consequent lack of heterogenity of this material. In some alloys this "dendritic" structure is so persistent that no ordinary heat treatment will obliterate it. It was in this connection that I went on to state in the same paragraph above quoted that in

the case of Armco ingot iron, any traces of dendrite boundaries that might still remain were "camouflaged" by the alpha structure.

As Professor Sauveur has pointed out it is the dendritic segregation which persists after the "granulation" of the dendrites themselves which makes it possible to reveal their former location. In the case of Armco ingot iron the impurities are so low that such segregation if its exists at all is so slight that etching will not reveal it.

It is very interesting to have Professor Sauveur's suggestions as to other possible causes of the "critical working range" in Armco ingot iron in addition to the iron sulphide hypothesis given in the paper. Inasmuch as the paper was essentially a compilation of the results of data and established facts, it was thought best to limit the explanation of the critical working range to the theory which is generally accepted at the present time. It will doubtless be necessary to modify this theory in the light of future research and such effects as Professor Sauveur has described will have to be taken into consideration in the formulation of the final explanation of the phenomenon.

The data given by Mr. Cain's discussion is an interesting comment on the availability of high purity iron in commercial quantities and shows that while electrolytic iron can be deposited in a slightly purer form than Armco ingot iron, it will lose this advantage if remelted even under extremely favorable conditions.

In commenting on Dr. Whittemore's discussion it should be said that an effort was made to include in the paper *all* of the published data on the physical properties of Armco ingot iron. The field is so wide, however, and the number of investigators so large that doubtless there have been some omissions, although this has been entirely unintentional. Any additional references that will enable an extension of the bibliography will be welcome.

In reply to Dr. Herty's criticism of the results of the chemical analysis given on page 3, I would say that the elements recorded are those which are customarily determined, known as the "Big 5". The value which is given for and plainly stated as "iron by difference" is shown to be based on the total of these five elements—carbon, manganese, phosphorus, sulphur, and silicon. The amount of oxygen in the metal depends upon the manner of working the heat in the furnace, the ladle additions, and the pouring conditions as well as other variables. A considerable part of the oxygen present in Armco ingot iron is in the form of oxide inclusions, which are readily seen by examination on the microscope. For some purposes, this is a decided advantage rather than a disadvantage. For example, in the case of sheets for vitreous enameling, these oxide inclusions assist in making a firm bond between the enamel and the base metal.

Professor Moore's point is well taken as to the method of stating the relationship between endurance limit and yield point. As brought out in the original paper and as emphasized by Professor Moore, the yield point appears to be the determining factor in the design of Armco ingot iron for all cases, including those where reversed flexure occurred.

Mr. Kurman, in his discussion, refers to the wide difference in requirements for steels of different magnetic properties for use in radio equipment.

It is probable that for such special applications as these, particularly vibrating reeds and armatures, in loud speaker units that physical and magnetic properties are both determining factors.

In regard to the first point mentioned by Dr. Ruder, I would say that the photomicrographs of Armco ingot iron shown in this paper are truly typical of thousands of different samples of Armco ingot iron which we have examined. The presence of oxide inclusions is plainly shown in all of them. This is particularly true of the photomicrographs shown on page 28.

Dr. Ruder also states that the permeability of Armco ingot iron is subject to wide variation on account of a very high aging effect. It has been our experience that the permeability is quite constant; in fact, it is only very slightly effected by wide variations in heat treatment. This statement applies to the permeability of Armco ingot iron at high inductions where it is used commercially and where the advantage of this material is most marked. It is a fact that Armco ingot iron is used for relay and armature parts by the largest manufacturers of automatic telephones in the world. In such instances a variation in permeability of 50 per cent such as mentioned by Dr. Ruder would be disastrous and would make its use impossible. This would seem to be sufficient evidence of the suitability of Armco ingot iron for commercial application where high permeability and low retentivity is required.

# THE IMPORTANT PROPERTIES AND REQUIREMENTS OF SOME SPECIAL REFRACTORIES

By M. F. Beecher

*Abstract*

*As higher temperatures are being used in various manufacturing processes it becomes continually more important that suitable refractories be obtained to withstand this increased demand on them. The author points out how fused alumina, silicon carbide and combinations of silica and alumina as now manufactured offer properties which are superior to those of the clay refractories which are so extensively used. These manufactured refractories are all electric furnace products and are obtained under a variety of trade names. The common causes of failure in refractories are also pointed out. Judging from particular requirements the most effective and economic refractories may be selected by knowing the properties which these manufactured products possess.*

IN THE general field of refractory materials those made from clay are still used very extensively and it is quite likely this will continue indefinitely. It is because most constructions requiring refractory materials do not have to withstand very severe conditions, that clay materials can meet the requirements quite economically. It is fortunate that this is so because clays of relatively high refractory character have been widely distributed by nature and are fabricated into refractory shapes in nearly every section of the country.

Within the past 15 years the service requirements in many furnace operations have become more and more severe, owing to the employment of higher temperatures and the speeding up of melting and heating cycles. It is not surprising, therefore, that during this period there has been considerable improvement in the quality of clay refractories. This has been accomplished both by the selection of clays of higher purity and also by the use of higher temperatures in firing. Today there are several manufacturers

A paper presented before the ninth annual convention of the society held in Detroit, September 19 to 23, 1927. The author, M. F. Beecher, is associated with the research laboratories of the Norton Company, Worcester, Mass. Manuscript received June 13, 1927.

producing firebricks made from kaolin grog bonded with kaolin and of clay-bonded diaspore. With bricks of this kind it is necessary to fire to much higher temperatures in manufacture in order to bring about, in the manufacturing operation, all or at least a major part of the normal shrinkage of these materials. Table I will show the general improvement in quality over the normal clay brick which can be effected by the use of kaolin or diaspore. It will be observed that the fusion point is very materially increased and the resistance to deformation in the load test is also much improved. The values given for the diaspore brick show the marked improvement in the load test results which is brought about by a higher firing temperature.

**Table I**
**Deformation at Various Temperatures**

| | Approx. Temp. of Cone Softening | Deformation under Load 1350 degrees Cent. 2460 degrees Fahr. 50 lbs. per square inch |
|---|---|---|
| Typical No. 1 fireclay brick | 1680 degrees Cent., 3056 degrees Fahr. | 7.1 per cent |
| Kaolin brick | 1750 degrees Cent., 3180 degrees Fahr. | *1.9 per cent |
| Diaspore brick | 1785 degrees Cent., 3245 degrees Fahr. | 5.8 per cent |
| Diaspore brick re-burned to cone 16 | 1785 degrees Cent., 3245 degrees Fahr. | 2.2 per cent |

*This load test was carried to a temperature of 1400 degrees Cent., 2550 degrees Fahr.

The same causes which operated to bring about the above described improvement in clay refractories also increased the interest in the development and improvement of refractories of mullite, bonded fused alumina and bonded silicon carbide. If one examines typical analyses of any of the clay materials mentioned above he is impressed with the fact that the two most refractory constituents shown are the silica and alumina which probably would suggest that if a refractory could be made of silica and alumina only, or better yet, of the more refractory of the two constituents alone, an excellent product would result. This is just what we have in the materials mullite and fused alumina.

Mullite is a compound normally produced artificially in the electric furnace. It consists of three molecules of alumina combined with two of silica. The fusion point of alumina taken alone is 2050 degrees Cent. (3720 degrees Fahr.), the fusion point of silica about 1700 degrees Cent. (3090 degrees Fahr.), while the fusion point of mullite is 1810 degrees Cent. (3290 degrees Fahr.). A further observation is interesting with respect to this compound, which is, that in normal clay refractories, heating to a high temperature or continued heating over long periods of time at temperatures above 1200 degrees Cent. (2190 degrees Fahr.), converts the silica and alumina originally present into the crystalline mullite which is found distributed as discrete but small crystals throughout the body of the ware. Additional mullite continues to form as the temperature or time of heating is increased until all of the alumina has been so combined; because all fireclays and kaolins contain excess silica over that required to combine with the alumina present in the formation of mullite. So in this material we have in some particulars the normal stable end product produced by prolonged heating of the usual clay refractory.

Mullite is not produced by nature in amounts of sufficient quantity to be of any commercial interest. It is made artificially by fusing a composition of silica sand and bauxite, or silica sand and alumina in an electric arc furnace of the same type as that used for producing fused alumina. A product high in mullite content (75 to 85 per cent) which is recently finding quite extensive use is made by calcination at high temperatures of such minerals as sillimanite, andalusite and cyanite. These minerals have the composition $Al_2O_3.SiO_2$, hence the calcined product contains an excess of silica which is present as glass.

Fused alumina is known under several brand names, such as "Alundum," "Aloxite," "Borolon," etc. It is normally produced in two general grades or qualities. Both are made in the arc-type electric furnace, a form of which is illustrated in Fig. 1. The furnace consists of a steel shell mounted on a carbon slab which in turn is carried on a small metal truck. The outside of the furnace shell is cooled by means of a water spray. The furnace is started by placing a small amount of the batch in the bottom, then introducing the electrodes. As the material melts more of the raw batch is added and the electrodes are gradually raised until the

furnace shell is filled to the brim with molten material. Water cooling of the metal shell prevents the fusion of a thin layer of the mixture on the inner side so that this unfused portion serves both as an insulator and as a refractory.

For the brown or regular "Alundum" grade of fused alumina the raw material used is bauxite to which is added the proper

Fig. 1—A Furnace Room Scene Showing the Type of Arc Furnace Used in the Manufacture of Fused Alumina.

amount of iron borings and coke in order to effect the desired degree of purification during smelting. The purer, or No. 38 "Alundum" grade, is produced by the straight fusion of precipitated alumina resulting from the chemical treatment of bauxite.

Fused alumina finds its principal field of usefulness in the abrasive industry. But it also has many properties which particularly commend it for use as a refractory. The electric furnace product consists of crystalline, artificial corundum together with a small amount of slag or accessory constituents. The abrasive characteristics can be varied to a marked extent by changing the size or physical structure of the crystals or by changing the kind or amount of the slag or accessory constituents. As a consequence, there are varied types of fused alumina abrasives available. To a

somewhat lesser extent it is possible to vary the physical and chemical characteristics of fused alumina in order to change the refractory characteristics which it contributes to the finished shape.

The fused alumina from the electric furnace is crushed in the usual manner with jaw crushers, rolls, etc., and the particles separated into various sizes by means of carefully regulated screening apparatus. It is washed to remove the dust and extraneous materials, magnetically separated to remove the iron constituents which are formed during fusion in the electric furnace, and is frequently further treated chemically to thoroughly clean the grain surfaces. The sized grains thus produced are mixed in the proper proportions for the particular grade of refractory desired and the proper quantity of a refractory ball clay, finely ground, is added. The quantity of clay will vary from 10 up to 25 per cent depending upon the particular properties desired in the finished article. For standard bricks and heavy shapes such as are used in heat treating furnaces the grit sizes employed run from about 14 mesh up to almost 200 mesh and the quantity of the bond used is about 10 per cent. The "Alundum"-clay mixture is now put in a kneading machine, three to five per cent of water is added, and the whole is thoroughly mixed. In this condition the mixture is such that the particles will adhere slightly under the pressure of the hand. The shapes are then made either by pressing in steel molds under hydraulic pressure or by tamping or ramming with air hammers into metal-lined wooden molds. The pressing method is employed wherever the shapes are sufficiently small or regular in outline as to make this means of forming economical and practical.

After a preliminary drying to remove the small amount of added water, the ware is placed in ceramic kilns and fired to cone 16 which corresponds to a temperature of about 1400 degrees Cent. (2550 degrees Fahr.) A protective coating to resist the attack of alkalies is sometimes employed. This is applied by spraying with an air gun before firing. With the increasing use of oil as a furnace fuel this matter is becoming of more importance.

Silicon carbide is a material which is not supplied by nature but is the discovery of Dr. Edward G. Acheson. It has no melting or softening point. At high temperatures, that is at 2250 degrees Cent. (4080 degrees Fahr.) it dissociates readily into the elements silicon and carbon. At lower temperatures beginning at about

800 degrees Cent. (1470 degrees Fahr.) it begins to oxidize appreciably. Between 1000 and 1200 degrees Cent. (1830-2190 degrees Fahr.) the oxidation is fairly rapid. At temperatures above 1200 degrees Cent. (2190 degrees Fahr.) one of the results of this oxidation is the development of a viscous coating which serves automatically to protect the silicon carbide and greatly retards the progress

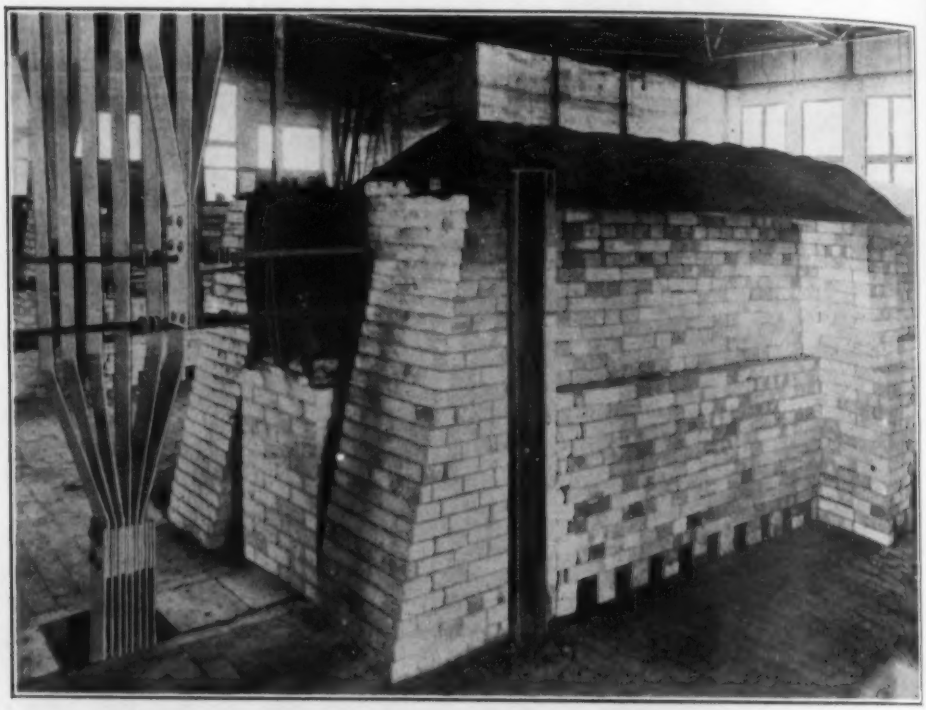

Fig. 2—The Resistance Furnace Used in the Production of Silicon Carbide.

of oxidation. Above this temperature, therefore, silicon carbide protects itself quite satisfactorily and becomes a very useful refractory. In order to increase the temperature range of usefulness and also to improve this normal protective coating which is formed, it is common practice for manufacturers to apply a glaze or relatively impervious coating to all silicon carbide shapes in order to retard the destruction of the refractory from this cause.

Silicon carbide is known under such trade names as "Crystolon" and "Carborundum." It is produced in electric furnaces of the resistance-type and is principally used as an abrasive, but because its chemical and physical characteristics particularly fit it for refractory work, its use in this field is rapidly increasing.

Silicon carbide is a chemical compound of silicon and carbon

and has the formula SiC. It is produced in a resistance furnace such as is shown in Fig. 2. The furnace charge consists essentially of silica sand, ground coke and sawdust. The silica sand provides the silicon and the coke the carbon necessary for the compound SiC. The function of the sawdust is to keep the mass in the furnace porous so that the large quantities of carbon monoxide gas produced can be readily liberated. In the course of the operation the gas is caused to burn at the surface of the batch, thereby eliminating all hazard to the attendants from gas poisoning.

The furnace product, after careful separation from the graphite and unconverted mixture, is crushed in the usual manner and the particles separated into various sizes. The methods of proportioning, mixing and molding are very similar to those employed in the manufacture of "Alundum" articles.

After a preliminary drying to remove the small amount of water which had been added to allow the mixture to be molded, a coating material to render the bricks impermeable to gases is applied. This is done with an air gun in the same manner as already described. The bricks are then placed in ceramic kilns and fired to a temperature of approximately 1400 degrees Cent. (2550 degrees Fahr.)

The firing operation serves to vitrify the clay bond, thereby thoroughly bonding or cementing together the silicon carbide particles. At the same time the coating which had been applied fuses to a dense porcelain-like structure and in the fired condition is, in one successful type, essentially a magnesium-aluminum silicate.

Perfect protection against oxidation during conditions of use within a temperature range of 800 to 1200 degrees Cent. (1470-2190 degrees Fahr.) can be accomplished only when a perfect coating on the ware is formed. Obviously this is impossible from a practical point of view, but manufacturers of this type of ware have so perfected the composition and application that difficulties from oxidation within the temperature range mentioned have been reduced to a minimum.

The four principal causes for failure in refractories may be classified as:

1. Plastic distortion
2. Permanent volume change (shrinkage or expansion)
3. Spalling
4. Chemical attack

It is obvious that plastic distortion of a refractory in use constitutes a definite failure. This defect may arise either from softening, because the combination of temperature and load have been too severe for the refractory used, or because the chemical composition has been altered by chemical attack, resulting in a lowered resistance to the temperature-load effect.

If one will refer again to the first item in Table I and observe the temperature interval which separates the cone softening from the deformation under load he will note that both load and temperature must be taken into account when considering this manner of failure. The cone in the fusion test and the brick in the load test both deformed because they were not sufficiently rigid at the temperature of test to overcome the force tending to produce deformation. In the first case it is merely the force of gravity, while in the second it is the force of gravity plus a load of 50 pounds per square inch. In both cases the refractory has deformed, in the first test at a temperature of 1680 degrees Cent. (3056 degrees Fahr.) and in the second at 1350 degrees Cent. (2460 degrees Fahr.)

Failure of a refractory because of permanent volume change is essentially failure of the furnace structure as a unit, for shrinkage or expansion which is not allowed for by some structural provision is sure to distort the furnace in such a manner as to bring about very serious results.

Clay brick, as a general thing, shrink appreciably during firing and if the temperature of service is higher than that at which the bricks were originally made, continued shrinkage is sure to follow. The amount of shrinkage is in fairly good accord with the amount of alumina present, thus high alumina bricks, so-called, are apt to show this defect unless originally burned at quite a high temperature. Silica bricks on the other hand, unless properly burned, exhibit a decided increase in volume in use. In addition to this, silica has a peculiar expansion behavior which must be taken care of by proper construction and heating up of the furnace. Silicon carbide, in general, shows expansion from two causes: that due to the absorption of heat which is a common property of all refractory materials and also a permanent expansion due to oxidation. As already mentioned, this last feature can be controlled or minimized quite satisfactorily by proper application of a protective

coating. These three instances are related as illustrating volume changes due to three separate and distinct causes. One case is that of a decrease in volume and the other two, increases in volume.

Failures due to spalling are rather serious in many types of construction. By spalling is meant cracking or rupture of a brick due to differential dimensional change, upon the absorption of heat, which exceeds the capacity of the brick to deform. If a refractory did not change in volume as it changed in temperature it could be heated and cooled in any manner and at any speed without rupture, or if it had an infinitely high thermal diffusivity or very high flexibility.

Spalling arises from the fact that when heat is absorbed by any refractory material one portion of the brick or piece expands more than another (because it is not possible to heat all portions at exactly the same rate) and to accommodate this differential change in volume the brick must either distort or break. Anything which will reduce the differential dimensional change within the brick upon absorption of heat or increase its flexibility will reduce spalling.

Failure of refractories through chemical attack does not always present such a simple problem as one might at first suspect. If an ash, dust, slag, gas or metal is to come in contact with the refractory it is advisable to consider specifically what reactions are possible between the constituents of the refractory and the material with which it comes in contact. Thus, for example, the alkalies react readily with silica and alumina and therefore have a serious effect on clay, fused alumina and silicon carbide. However, magnesia would be quite resistant and would be the proper choice of a refractory in such a case. Oxides of iron at sufficiently high temperatures will slag readily with fused alumina or silicon carbide, so that chrome, magnesia or zirconia bricks would be a better selection.

In considering the chemical behavior of the refractories it is well not to lose sight of the fact that there are two features of importance in addition to those just mentioned. That is, two features which control or limit the amount of reaction which can take place and which might modify the decisions made on the basis of chemical reactions only. These are, first, the structure of the refractory, and second, the physical and chemical characteristics of the product resulting from the reaction.

Where the material coming into contact with the refractory is liquid, for example, a dense impervious refractory will have much longer life, because a lesser surface is exposed and in consequence the speed of reaction is greatly retarded. An example of this is readily observed in the case of refractory blocks used for building glass tanks. A very marked difference in life is observed as between dense and open structure refractories. In addition to having a much shorter life tank blocks of open porous structure also contaminate the glass to a much greater extent.

**Table II**
**Physical Properties of Some Special Refractories**

| | Approx. Temperature of Softening | Deformation in Load Test 1500 degrees Cent., 2730 degrees Fahr. 50 lbs. per square inch | Resistance* to Spalling |
|---|---|---|---|
| "Alundum" fused alumina | 1835 degrees Cent., 3335 degrees Fahr. | 2.0 per cent | 3 |
| "Crystolon" silicon carbide | Does not soften appreciably. | .1 per cent | 10 |
| Mullite | 1800 degrees Cent., 3272 degrees Fahr. | 1.1 per cent | 3 |

*Number of cycles—heating to 1350 degrees Cent., 2460 degrees Fahr., and cooling in an air blast.

It sometimes happens that the product of reaction is saturated with respect to the refractory itself and is also of a viscous or pasty consistency so that it remains upon the surface exposed and in this manner serves as a protective coating. This is illustrated in the case of silicon carbide at temperatures above 1200 degrees Cent. (2190 degrees Fahr.) as has already been described.

Some of the characteristics of the special refractories particularly discussed in this paper are given in Table II.

By comparison with Table I the higher softening point and greater resistance to deformation under load became apparent. It should be noted that in Table II the load test was conducted at 1500 degrees Cent. (2730 degrees Fahr.), for at the lower temperatures used for the materials reported in Table I, no measurable

deformations would have resulted. The superiority, therefore, of "Alundum," "Crystolon" and mullite refractories over even the high grade clay materials with respect to resistance to plastic deformation is clearly shown.

The second common cause for refractory failure, that of permanent volume change during service, is also brought to the very minimum. "Alundum," "Crystolon" and mullite, being electric furnace products, have been reduced to ultimate density before being bonded into the finished article. The fused alumina, for example, is completely preshrunk, as is also the mullite. No further shrinkage can take place during use and no expansion. The silicon carbide likewise cannot shrink during subsequent service and its tendency to expand or "grow" when used at low temperatures under oxidizing conditions is minimized by the use of a proper glaze or coating.

In resistance to spalling, silicon carbide is at present appreciably superior to either fused alumina or mullite, though experiments leading to the development of better bonded articles of these last named materials are giving promise of success.

The refractory, ideal for all conditions, has not yet been produced. Intelligent selection of the type best suited to each particular job is still necessary. And to make such a selection it is essential that the most likely causes for failure in each installation be known, so that the refractory may be chosen in accordance. Hence it has been the purpose of this paper to point out the generally important causes for refractory failures and the essential characteristics of the more important refractories available, in the hope that by a study of furnace requirements in this manner a more effective and economical use of refractories may be made.

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## DISCUSSION

**Written Discussion:** By J. C. Woodson, Industrial Heating Engineering Department, Westinghouse Electric and Manufacturing Co., Mansfield, Ohio.

This paper enters a field where little technical data is available and I believe gives some information of considerable value to engineering concerns interested in this class of product. However, I would like to see more technical data presented in the nature of all the physical and electrical properties of this material so that you could have this data for reference when considering the use of one or more of these items. The Westinghouse Company has had some experience with the use of carbofrax brick when used in an

electric welding furnace. It was found that the borax used for fluxing the metal, readily attacked the carbofrax plates and caused them to fuse down at temperatures in the neighborhood of 2400 degrees Fahr., whereas under ordinary conditions this material would not soften at temperatures very much higher than this. This bears out the statements made by Mr. Beecher that these special refractories are affected more by chemical reaction in the furnace than by temperature alone.

We have also used different carborundum mixtures for resistor elements in electric furnaces, but found that the resistance and other electrical qualities of this material varied greatly with different samples. As a matter of fact, there was such a lack of uniformity that the experiments were abandoned. This, of course, is somewhat aside from the normal use for which they are manufactured, but it simply points out that other uses of this material may be developed provided better control of the manufacture is accomplished.

Mr. Beecher's statement about using a protective glaze on the surface of these refractories is quite interesting. I would be pleased to know the nature of this glaze and at what temperatures it can be used, as I believe there are a number of places where such a protective coating would be useful in electric furnaces.

We have had considerable experience with various types and kinds of linings for melting furnaces including linings made of carborundum brick, and while the better class of brick such as carborundum undoubtedly shows greater life than the fireclay brick, our experience has indicated that this increased life is not sufficient to justify the difference in cost. Another disadvantage was that those bricks used around door openings and electrode port holes seem to oxidize at electric furnace temperatures rather rapidly, although the bricks in the main part of the wall stood up better than fireclay brick. Undoubtedly great strides have been made in the improvement of refractories in the last few years, but a great deal more research work should be done along this line to develop brick of greater uniformity, also with less shrinkage and tendency to spall with temperature changes and at lower prices, as there will never be a very general use of these better refractories until the price per thousand hours of life compares with the price of ordinary fireclay bricks.

J. A. KING: I would like to ask Mr. Beecher regarding that last table if I was correct in assuming that the spalling loss on fireclay was greater than it was on either the alundum or the silicon carbide.

M. F. BEECHER: In some cases yes, Mr. King. Out of ten or a dozen commercial kinds of firebrick one might get spalling losses in a method of test comparable to this that would run all the way from 8 to 18. We have seen fireclay brick that have run up to 30 cycles in this same test, and others, again, that run down as low as 6.

J. A. KING: The reason I asked that is that Dr. Hartmann found (*Journal*, American Electrochemical Society; *Journal*, American Ceramic Society), the spalling loss on the carbofrax brick was very much less than on any general type of clay brick, and the spalling loss on the clay brick, in general, ran less than they did on the alundum brick.

(*Continued on Page* 492)

# HIGH SPEED, HIGH VOLTAGE X-RAY DIFFRACTION ANALYSIS OF METALS

By Dr. Ancel St. John

*Abstract*

*A quick and convenient method of X-ray diffraction analysis has been developed. It is a modification of the usual "pinhole" method using tungsten radiation at 200,000 volts as in radiographing castings, so that a powerful beam passes through 1/8 inch of steel. If desired, entire sheets or formed articles can be mounted in the instruments or specimens can be cut without affecting the portion to be examined. Exposures of two hours or less are sufficient. The method has been applied to brass, tin and steel in the study of mechanical working, heat treatment, extrusion, aging and the effect of exposure to gases. Radiographic examination of steel and brass castings for high pressure service has been carried on simultaneously. Some typical results are illustrated.*

SPEED and convenience are two most important characteristics of any method of routine testing. Many tests which are common practice in research laboratories are impractical for plant control because too slow or cumbersome, while others are seldom used even in research for the same reasons. X-ray diffraction analysis has been handicapped in both these respects. With the usual methods it has been necessary to make very long exposures or to exercise great care in preparing specimens. On this account the writer has directed much attention during the past year to the development of a method which is reasonably quick and very convenient. The usual exposure time is two hours or less. With appropriate mechanical arrangements large metal sheets and many kinds of formed articles can be tested without cutting out a specimen. Thus extruded tubing has been examined "as received."

The only novelty in the method is the use of extremely high voltages such as are employed for radiographic examination of steel castings and the like. The power plant, tube, and protective

A paper presented before the ninth annual convention of the society held in Detroit, September 19 to 23, 1927. The author, Dr. Ancel St. John, a member of the society, is a consulting physicist, New York City. Manuscript received August 15, 1927.

equipment are those already described elsewhere by the writer.[1,2] The diffractometers are of the usual "pinhole" type as originally used by Friedrich and Knipping in demonstrating the existence of X-ray diffraction. They are modified by using ¼-inch lead for the shields containing the pinholes and by having the two shields mounted in a tube movable longitudinally along the beam and provided with appropriate devices for holding the specimens in place against a stop at a fixed distance from the photographic film. The film is contained in a removable cassette which is provided with a lead shield to intercept the direct beam. This shield is marked so as to identify the instrument and the orientation of the film. At present a group of four such instruments are mounted on a lead-covered steel drum containing the X-ray tube in a region not ordinarily used for radiographic work, so that both classes of work can be carried on either independently or simultaneously as may be convenient.

Some idea of the quality of the results and the sort of information obtainable can be gained from the accompanying illustrations. In all cases the distance from the target to the specimen was about 20 inches and from specimen to film about 4 inches, the voltage 200,000 and the current 4 milliamperes. The times were as stated in each case. Fig. 1, exposure 1 hour (a), compares a sheet of 1/16-inch soft brass, (b) an article formed from this and (c) such an article after annealing. The original material consists of fairly large grains arranged completely at random, as shown by the random arrangement of speckles. The forming operation has produced very fine grains oriented in a definite manner, as shown by the diffuse rings with local intensifications in symmetrical positions. The annealing has caused considerable grain growth and a modification of grain orientation, as shown by the streaks and the new symmetry. These specimens were each more than an inch square so that any metal affected by cutting out the specimens was at least ½ inch from the small portion actually in the X-ray beam, which was only 1/50 inch in diameter.

Fig. 2, exposures 1 hour, represents a study of extruded tubing in which (a) and (b) were made from a piece of the tubing as received, soon after receipt, and a month later, while (c) is from

[1] *Iron Age.*

[2] *Industrial and Engineering Chemistry,* Vol. 19, p. 339, March 1927.

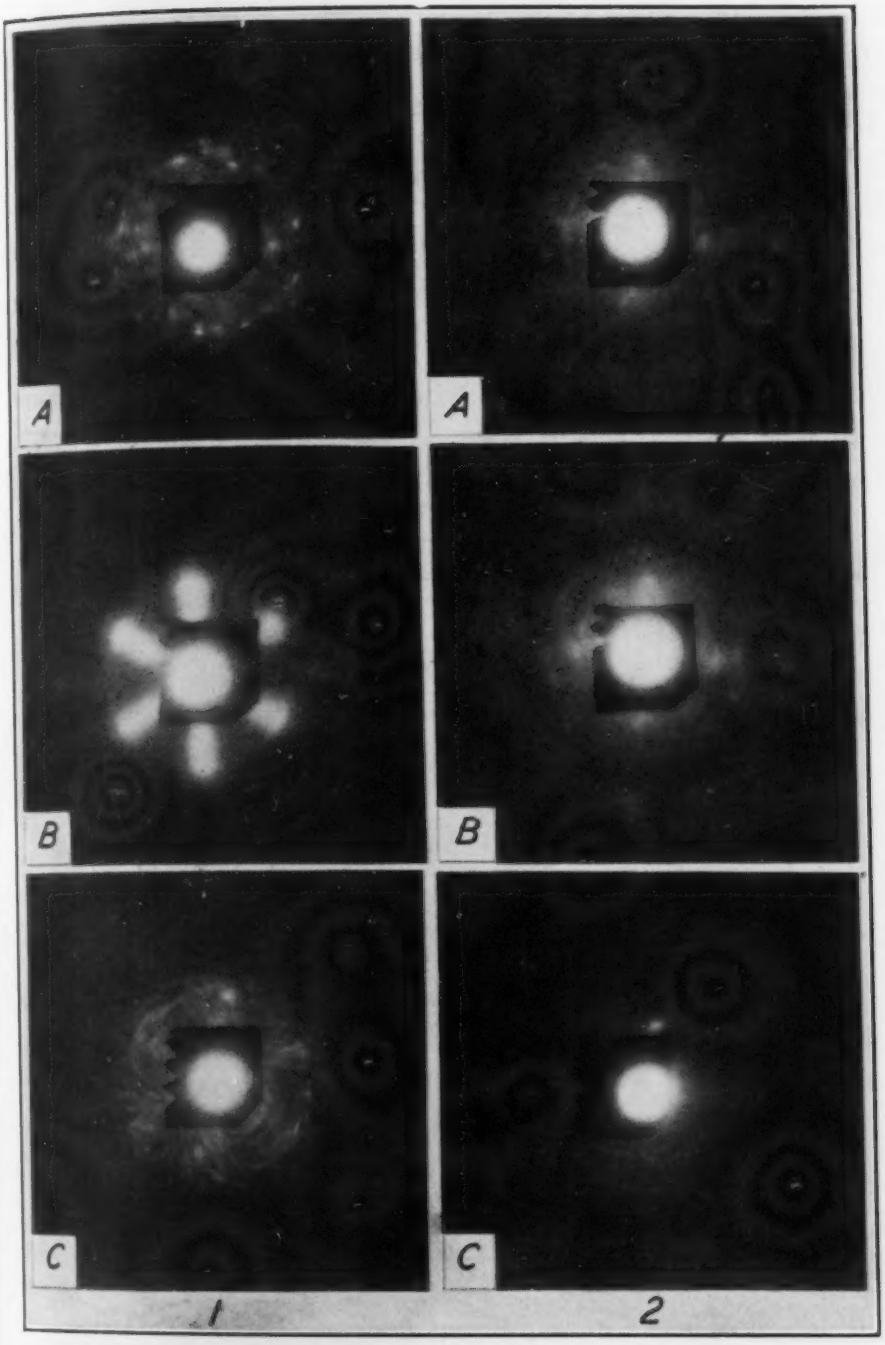


Fig. 1—X-ray Photographs of a Piece of 1/16 Inch Brass (a) Soft Brass, (b) Article Formed from the Brass, (c) Same Article After Annealing. Fig. 2—X-ray Photographs of Extruded Tubing, (a) As Received, (b) As Received but One Month Later, (c) Portion of Another Tube Tested Hydrostatically to Failure.

a portion of another tube which had been tested hydrostatically to failure. The aging has produced absolutely no change in the patterns, the slight haziness in (b) being as marked for the shadow of the shield as for any part of the pattern, whereas the cold working in the hydrostatic test has completely changed the character of the pattern. In Fig. 3, exposures 2 hours, (a) is 1/8-inch Armco iron from a vessel which failed through nitrogen embrittlement, (b) is a piece of new Armco iron of the same thickness and (c) is the pattern from directly on the bend of a portion immediately adjacent to the specimen for (b) which has been bent 90 degrees. The scale on the new iron shows some striations which were placed so that they were parallel to the vertical edges of the marker. These evidently correspond to the direction of rolling and the material has not been annealed. In the embrittled sample the doubling of the pattern in places suggests twinning and there are indications of grain growth. The bending does not seem to have modified the structure notably. Fig. 4 (a), exposure 4 hours, represents a portion of a ¾-inch hexagonal nut which had cracked, probably due to nitrogen embrittlement. The average thickness where examined was 3/16 inch, which accounts for the long exposure and to some extent for the lack of definition in the pattern. The material is evidently very fine-grained and there seems to be a definite symmetry. For (b) and (c) the exposure was 2 hours and the material 0.014-inch transformer iron, parts of a single strip direction of rolling parallel to vertical edges of marker. Radiograph (b) represents the normal material and (c) a region where the sheet had been bent back and forth with the fingers about half a dozen times. In the original material the large speckles and the random distribution indicate thorough annealing. The small amount of cold working due to the flexing has refined the grains somewhat and has introduced a definite symmetry about a horizontal line. The axis of bending was in the same direction.

Fig. 5 is a radiograph of a portion of a steel casting 1-3/16 inch thick made in an exposure of 25 seconds with the same sort of radiation. The object was 30 inches from the target and the film about 3 inches from the object. The light streaks show shrinkage cracks of considerable extent. The dark band is a strip of thin lead foil attached to the casting in which identification marks were

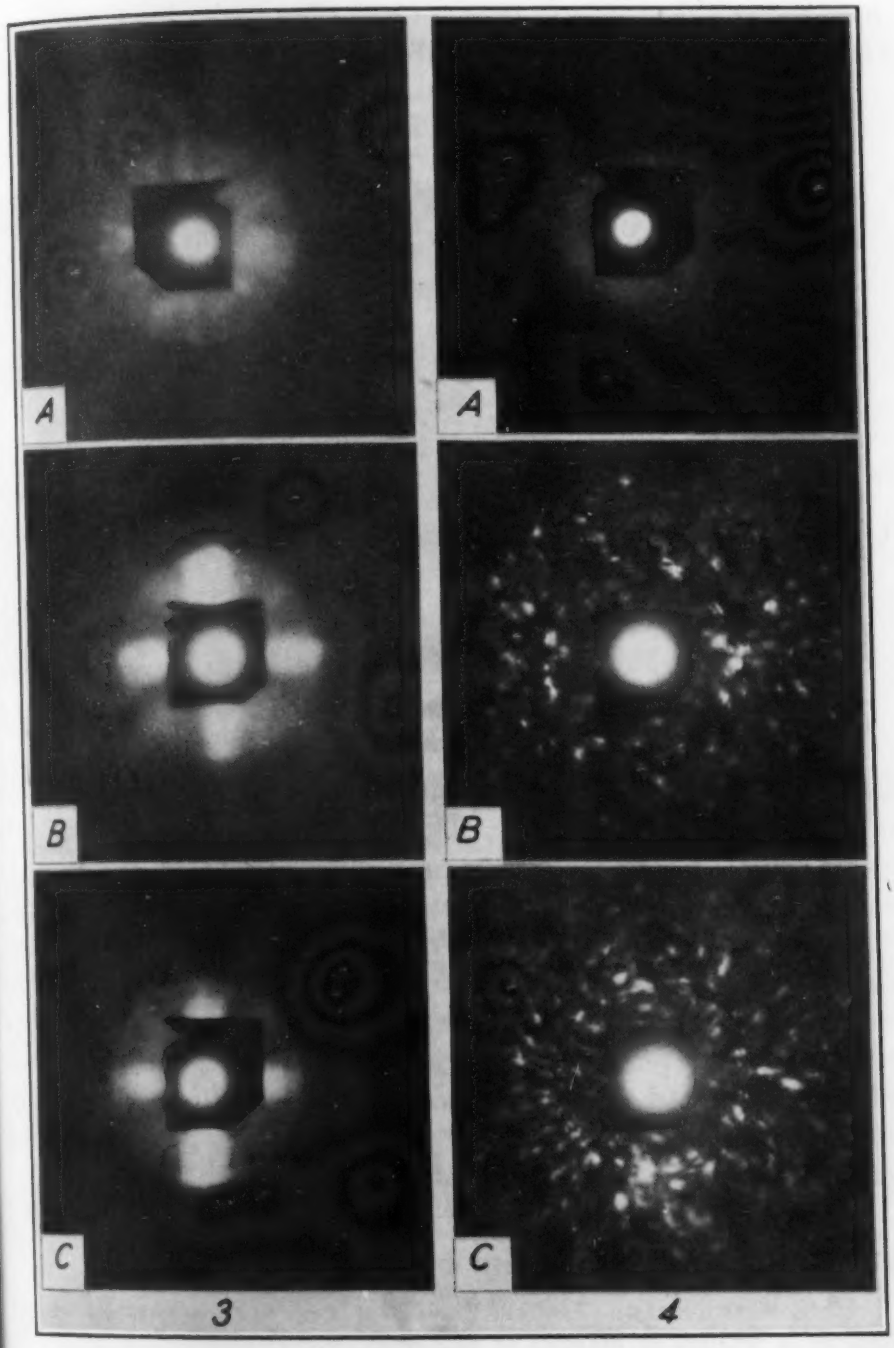


Fig. 3—X-ray Photographs of Armco Ingot Iron, (a) ⅛ Inch from a Vessel which Failed Due to Nitrogen Embrittlement, (b) ⅛ Inch New Material, (c) Pattern of Bend Adjacent to Specimen (b). Fig. 4—X-ray Photographs of (a) ¾ Inch Hexagonal Nut, Cracked Probably Due to Nitrogen Embrittlement, (b) .014 Inch Transformer Iron, Normal Material, (c) Section Which has been Bent Back and Forth with the Fingers.

punched. This radiograph was part of a series made in routine inspection without disturbing the diffractometers.

The results thus far secured show that the method is reasonably rapid, requires little or no attention to preparation of speci-

Fig. 5—Radiograph of a Portion of a Steel Casting 1 3/16 Inches Thick, Made with an Exposure of 25 Seconds.

mens and gives patterns representative of the body of the material rather than of the surface. This is particularly important. It makes it possible to examine a particular portion of an article, to subject it to various treatments and to examine it at each stage, thus securing a coherent record on a single original specimen and eliminating the possible variation from specimen to specimen. By reducing dimensions it should be possible to cut the exposure time to one-half or even to one-quarter so that the elapsed time from beginning to load the diffractometer to completing the development of the film will be under an hour. The possibilities as a control test are thus most interesting.

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## DISCUSSION

R. S. MacPherran: I would like to ask Dr. St. John what thickness of metal it is feasible to examine in this way.

Dr. St. John: The greatest I have examined is that 3/16 inch piece of steel, a portion of a hex nut, and that required a four-hour exposure for a good picture. I am at the present time working on reducing the dimensions of the equipment so as to take advantage of the fact that under the inverse square law, whenever we halve a distance, we cut down our required exposure

time to one-fourth, and in that way I hope to speed the test up considerably.

R. S. MacPHERRAN: I had reference to the last picture. How thick was that steel?

DR. ST. JOHN: You have reference to the radiographic work. That was 1⅛ inches thick and a 25-second exposure.

R. S. MacPHERRAN: How thick a piece can you examine by that means?

DR. ST. JOHN: I have examined 3¾ inches with that apparatus. In that case I had to take a 1-hour exposure.

G. W. WALKER: If you were to examine specimens of clean and dirty steel, could you differentiate between them?

DR. ST. JOHN: I really don't know. I rather have my doubts. I pointed out that this is by no means a precision method with respect to structure, and the determination of clean or dirty steel is decidedly one of the precision methods with respect to the crystal structure of the components.

G. W. WALKER: Well, in the case of slag, for instance. Oftentimes you find slag inclusions that are .015 of an inch in length.

DR. ST. JOHN: On the radiograph they might possibly show. In diffraction analysis there wouldn't be enough material.

G. W. WALKER: There is no possibility of magnifying an inclusion so that you could locate it, is there?

DR. ST. JOHN: Unfortunately, no. If I could put out an X-ray microscope, I could retire within two years.

C. T. PATTERSON: Dr. St. John should be congratulated on the progress that he has made in applying X-rays to industry. We had some high-pressure steel castings inspected by him and the result was unique. We wanted to know just how good the X-ray inspection was. We were in doubt about it. So we asked our inspector to go to the foundry and pick out an average casting for examination. Well, it seems he misunderstood our instructions and he picked out what he thought was the best, and that was sent to Dr. St. John. He examined it and came to us with a surprising story that he was hardly able to believe himself. He said, "That casting is rather less than a half inch thick on one side and an inch and one-half thick on the other—".

DR. ST. JOHN: Over an inch thick.

C. T. PATTERSON: Well, it was supposed to be about an inch thick. "Furthermore," he said, "there is a big sand pocket in there and there is a crack from the sand pocket that is more than half the thickness of the metal at that point." In addition to that, he picked out quite a number of other defects, cracks, blow holes, shrinkage cavities, etc.

Well, being our first experience, we were skeptical, so we took the casting and cut it up, and we found that on the thin side it was 7/16 of an inch thick, he had missed it by only 1/16, and on the thick side it was 1¼ inches. We found every crack and every blowhole and sand cavity just where he marked it on the outside of the casting with his pencil.

Now, that is quite an achievement, considering that this was a casting which the inspector who examined it visually thought was an especially good one.

DR. ST. JOHN: Since Mr. Patterson has mentioned that, I will say that that particular casting was picked out so as to have a good one, because I had already rejected two that were bad, and they thought they would like to see what a good one looked like. I had also passed two for use although they actually had defects in them, but those defects were of a permissible character. Later on, under high pressure service, I believe they are going to leak, there were sort of sinuses connecting small gas pockets,—but there were no dangerous areas, whereas this particular piece had, not a small portion, but quite an extended area that had a condition as shown, and if it had been put into service, some fine day or some fine night would have caused an explosion and the Lord only knows what would have happened then.

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## THE IMPORTANT PROPERTIES AND REQUIREMENTS OF SOME SPECIAL REFRACTORIES

(*Continued from Page* 484)

**Author's Reply to Mr. Woodson's Comments:** One protective coating which is successfully employed is essentially a magnesium-aluminum silicate. It is formed on the surface during manufacture and at a temperature of about 2550 degrees Fahr. (1400 degrees Cent.). Another coating, also covered by patent, which has found some favor has a composition essentially that of a high temperature porcelain body. As a coating for a refractory material, it is obvious that the temperature of formation should be very high; preferably as high as the temperaure at which the refractory is to be used, but certainly safely above 2200 degrees Fahr. (1200 degrees Cent.) which is approximately the upper limit of the temperature range where protection against oxidizing gases is very essential.

# Comment and Discussion

Papers and Articles Presented Before the Society and Published in Transactions Are Open to Comment and Discussion in This Column

## DISCUSSION OF ROGER SUTTON'S PAPER "A STUDY OF SOME OF THE CAUSES OF FAILURE IN HEAT RESISTING ALLOYS"[1]

By David Evans[2]

WE have read with considerable interest the article by Mr. Roger Sutton in August, 1927, issue of Transactions entitled A Study Of Some Of The Causes Of Failure In Heat Resisting Alloys. Mr. Sutton's article shows plainly how misleading it is to buy heat resisting alloys on the strength of the nickel and chromium content alone, as is frequently done. The best analysis in the world in the hands of poor foundrymen will usually produce poor results.

It is the physical characteristics which determine the value of the article in actual use, and these characteristics can be most certainly secured from a foundry which has had experience in the foundry business before they attempt to make alloy steels.

Many manufacturers of alloy steels pin their faith to a formula which covers the chemical analysis only and do not pay sufficient attention to physical characteristics. The bare analysis of the metal may be likened to the roof of a house—of course a roof is necessary, but it is not much use without a foundation and walls to support it. Because certain metals have been found to be valuable alloys when added to steel is no reason for supposing that a steel containing the maximum amount of such alloys is the best for the purpose. Bread is undoubtedly a good thing, but "Man may not live by bread alone."

Mr. Sutton gives the complete analysis of five carburizing boxes, showing nickel from 47.93 to 60.61 per cent, chromium from 13.70 to 22.58 per cent, silicon from 1.28 to 4.77 per cent. He does not say that all the boxes were from the same manufacturer, or supposed to be of the same grade, if they were, they show inexcusable carelessness in making up the "heat," because there is far too much variation in the analysis. One only, out of the five boxes, gave satisfactory results as to heat hours, and that one was very good indeed. Of the remaining four, one of them gave about half the hours of service one could reasonably expect, two of them were not much better than ordinary cast steel and the fifth not as good as the cheapest cast iron. It would be interesting and illuminating to know something about the foundry practice which was followed in making these

[1] Roger Sutton, "A Study of Some of the Causes of Failure in Heat Resisting Alloys," Transactions, American Society for Steel Treating, Vol. XII, August, 1927, page 221.

[2] The author of this discussion, David Evans, is president of the Chicago Steel Foundry Co., Chicago.

boxes; the preparation of the molds, whether green or dry, the position of the pattern in the mold, whether made the easiest way, i. e., with the bottom up and forming its own core, or with the mouth up and with a cover-core. The temperature of the steel when the alloys were added and whether they were pure virgin quality, or either wholly or in part scrap from a previous heat of what was supposed to be the same grade of metal.

The point to these questions is to show that chemical without physical analysis tells only part of the story. It is important but there are other factors of equal importance.

The failure of these four boxes which made such a poor showing was due, no doubt, to physical defects. While there was too great a variation in chemical content of various elements, assuming, of course, that they were supposed to be the same in each case, still any one of the several analyses would have produced far better results if proper care had been used in the foundry.

Many buyers of heat resisting alloys assume that the ones containing the largest percentage of nickel and chromium are the best. There are at least four alloys in heat resisting steel which play an important part. Obviously, that combination of these alloys most readily assimilable by the bath of steel and which in actual practice gives the greatest number of heat hours per dollar of investment is the proper combination to use. Hundreds of buyers are today given opportunities to prove to their own satisfaction that alloys containing the highest percentages of nickel and chromium are not necessarily the best. On the contrary they are frequently not quite as good as an alloy containing a somewhat lower percentage of nickel and chromium but where proper attention has been given to every detail of manufacture.

In the sale of heat resisting alloys we believe, and hope, the "debunking" stage has arrived. Spectacular selling methods, glib sales talk, reckless guarantee and all the rest of it, will go the same way such methods have disappeared in the sale of other merchandise. In many instances consumers have not stopped to think how unreasonable it is to expect a man with nothing but an analysis to be able to produce steel castings of exceptional quality, when they know, most of them, that to produce even a good plain carbon steel casting takes rather exceptional skill and a thorough knowledge of the art. It is very necessary that before steel foundrymen can hope to make a good alloy steel they must know how to make good castings. Here is a boy who can't even stand on his head, but he is given a balancing pole and expected to perform on the slack wire—it can't be done.

The chief metallurgist for one of our largest corporations said to this writer not long ago, "foundry practice is 75 per cent of the game." He had been having his trouble probably and that is why he put the practice at 75 per cent. I hesitate to place any given percentage against any one factor, but I do know, from years of experience in this most fascinating department of steel founding, that good foundry practice is certainly a most indispensable part of the whole and to neglect it means certain failure.

## STANDARD SAMPLES ISSUED BY THE U. S. BUREAU OF STANDARDS

THE U. S. Bureau of Standards is now prepared to furnish the standard samples listed below. Attention is particularly called to the new standard samples of acid potassium phthalate, arsenious oxide, dolomite, glass sand, lead-barium glass and ferrotungsten.

| Sample number | Name | Constituents determined or intended use | Weight of sample in grams | Fee per sample |
|---|---|---|---|---|
| 88 | Dolomite | Complete analysis | 50 | $2.00 |
| 70 | Feldspar | Complete analysis | 40 | 2.00 |
| 80 | Glass, soda-lime | Complete analysis | 45 | 2.00 |
| 89 | Lead barium glass | Complete analysis | 45 | 2.00 |
| 76 | Burnt refractory (40% $Al_2O_3$) | Complete analysis | 60 | 2.00 |
| 77 | Burnt refractory (60% $Al_2O_3$) | Complete analysis | 60 | 2.00 |
| 78 | Burnt refractory (70% $Al_2O_3$) | Complete analysis | 60 | 2.00 |
| 81 | Glass sand | $Fe_2O_3$, $Al_2O_3$, $TiO_2$, $ZrO_2$, CaO, MgO | 60 | 2.00 |
| 2 | Zinc ore D | Zinc | 50 | 1.00 |
| 25b | Manganese ore | Manganese, available oxygen | 100 | 2.00 |
| 26 | Crescent iron ore | $Al_2O_3$, CaO, MgO | 100 | 2.00 |
| 27a | Sibley iron ore | $SiO_2$, P, Fe | 125 | 2.00 |
| 28 | Norrie iron ore | Mn (low) | 50 | 1.00 |
| 29 | Magnetite iron ore (titaniferous) | Complete analysis | 50 | 1.00 |
| 56 | Phosphate rock | $P_2O_5$, $Fe_2O_3$, $Al_2O_3$, etc. | 60 | 2.00 |
| 69 | Bauxite | Complete analysis | 60 | 2.00 |
| 71 | Calcium molybdate | Mo, Fe, Ti | 60 | 2.50 |
| 4c | Cast iron | C, Mn, P, S, Si, Ti, (Cu, Ni, Cr, V) | 150 | 2.50 |
| 5e | Cast iron | C, Mn, P, S, Si, Ti, (Cu, Ni, Cr, V) | 150 | 2.50 |
| 6d | Cast iron | C, Mn, P, S, Si, Ti, (Cu, Ni, Cr, V) | 150 | 2.50 |
| 7b | Cast iron | C, Mn, P, S, Si, Ti, (Cu, Ni, Cr, V) | 150 | 2.50 |
| 55 | Ingot iron | C, Mn, P, S, Si, Cu, Ni | 150 | 2.00 |
| 74 | Cast iron | C, Mn, P, S, Si, Ti, (Cu, Ni, Cr, V) | 150 | 2.50 |
| 82 | Nickel-chromium cast iron | C, Mn, P, S, Si, Cr, Ni (Ti, Cu, V) | 150 | 2.50 |
| 8c | Steel, Bessemer, 0.1 C | C, Mn, P, S, Si, (Cu, Ni, Cr, V) | 150 | 2.00 |
| 9c | Steel, Bessemer, 0.2 C | C, Mn, P, S, Si, (Cu, Ni, Cr, V) | 150 | 2.00 |
| 10d | Steel, Bessemer, 0.4 C | C, Mn, P, S, Si, (Cu, Ni, Cr, V) | 150 | 2.00 |
| 22b | Steel, Bessemer, 0.6 C | C, Mn, P, S, Si, (Cu, Ni, Cr, V) | 150 | 2.00 |
| 23a | Steel, Bessemer, 0.8 C | C, Mn, P, S, Si, (Cu, Ni, Cr, V) | 150 | 2.00 |
| 15b | Steel, B. O. H., 0.1 C | C, Mn, P, S, Si, (Cu, Ni, Cr, V, As) | 150 | 2.00 |
| 11c | Steel, B. O. H., 0.2 C | C, Mn, P, S, Si, (Cu, Ni, Cr, V, As) | 150 | 2.00 |
| 12c | Steel, B. O. H., 0.4 C | C, Mn, P, S, Si, (Cu, Ni, Cr, V, As) | 150 | 2.00 |
| 13c | Steel, B. O. H., 0.6 C | C, Mn, P, S, Si, (Cu, Ni, Cr) | 150 | 2.00 |
| 14b | Steel, B. O. H., 0.8 C | C, Mn, P, S, Si, (Cu, Ni, Cr, V) | 150 | 2.00 |
| 16b | Steel, B. O. H., 1.0 C | C, Mn, P, S, Si, (Cu, Ni, Cr, V, As) | 150 | 2.00 |
| 19b | Steel, A. O. H., 0.2 C | C, Mn, P, S, Si, (Cu, Ni, Cr, V) | 150 | 2.00 |
| 20c | Steel, A. O. H., 0.4 C | C, Mn, P, S, Si, (Cu, Ni, Cr, V) | 150 | 2.00 |
| 21b | Steel, A. O. H., 0.6 C | C, Mn, P, S, Si, (Cu, Ni, Cr, V) | 150 | 2.00 |
| 34 | Steel, A. O. H., 0.8 C | C, Mn, P, S, Si, (Cu, Cr, Mo) | 150 | 2.00 |
| 35a | Steel, A. O. H., 1.0 C | C, Mn, P, S, Si, (Cu, Cr) | 150 | 2.00 |
| 51 | Steel, electric furnace, 1.2 C | C, Mn, P, S, Si, (Cu, Ni, Cr, V) | 150 | 2.00 |
| 65 | Steel, acid electric | C, Mn, P, S, Si, (Cu, Ni, Cr, V) | 150 | 2.00 |
| 30b | Steel, chrome-vanadium | C, Mn, P, S, Si, Cr, V, (Cu, Ni) | 150 | 3.00 |
| 32b | Steel, chrome-nickel | C, Mn, P, S, Si, Cr, Ni, (Cu) | 150 | 3.00 |
| 33a | Steel, nickel | C, Mn, P, S, Si, Ni, (Cu, Cr, V) | 150 | 3.00 |
| 50 | Steel, chrome-tungsten-vanadium | C, Mn, P, S, Si, W, Cr, V, (Cu, Mo) | 150 | 3.50 |
| 72 | Steel, chrome-molybdenum | C, Mn, P, S, Si, Cr, Mo, (Cu, V) | 150 | 3.00 |
| 73 | Steel, stainless | C, Mn, P, S, Si, Cr, (Cu, V, Mo) | 150 | 3.00 |

| | | | | |
|---|---|---|---|---|
| 57 | Refined silicon | Complete analysis | 60 | 2.00 |
| 58 | Ferrosilicon (75% silicon) | Complete analysis | 75 | 2.00 |
| 59 | Ferrosilicon (50% silicon) | Complete analysis | 75 | 2.00 |
| 61 | Ferrovanadium (high carbon) | Complete analysis | 100 | 3.00 |
| 64 | Ferrochromium (high carbon) | Complete analysis | 100 | 3.00 |
| 66 | Spiegeleisen | Complete analysis | 100 | 2.00 |
| 67 | Manganese metal | Complete analysis | 100 | 2.50 |
| 68 | Ferromanganese | Complete analysis | 100 | 2.50 |
| 75 | Ferrotungsten | W, C, Mn, P, S, Si, Sn, As, Mo, Cu, Sb | 150 | 4.00 |
| 37b | Brass, sheet | Complete analysis | 150 | 3.00 |
| 52 | Bronze, cast | Complete analysis | 150 | 3.00 |
| 53 | Lead-base bearing metal | Complete analysis | 200 | 3.00 |
| 54 | Tin-base bearing metal | Complete analysis | 200 | 3.00 |
| 62 | Manganese bronze | Complete analysis | 150 | 3.00 |
| 63 | Phosphor-bronze bearing metal | Complete analysis | 150 | 3.00 |
| 42b | Tin | Melting point 231.9° C. | 350 | 2.00 |
| 43b | Zinc | Melting point 419.4° C. | 350 | 2.00 |
| 44b | Aluminum | Melting point 658.9° C. | 200 | 1.00 |
| 45a | Copper | Melting point 1083° C. | 450 | 2.00 |
| 49 | Lead | Melting point 327.3° C. | 1650 | 2.00 |
| 46m | Cement (normal) | Fineness (testing sieves) | 160 | 1.00 |
| 47d | Cement (extra fine) | Fineness (testing sieves) | 160 | 1.00 |
| 84 | Acid potassium phthalate | Acidimetric value | 60 | 3.00 |
| 39c | Benzoic acid | Acidimetric and calorimetric values | 30 | 2.00 |
| 40b | Sodium oxalate | Oxidimetric value | 60 | 2.00 |
| 83 | Arsenious oxide | Oxidimetric value | 75 | 2.00 |
| 38a | Naphthalene | Calorimetric value | 50 | 2.00 |
| 17 | Sucrose | Calorimetric and saccharimetric values | 60 | 2.00 |
| 41 | Dextrose | Reducing value | 70 | 2.00 |

Information as to the history of the standard samples, their use in checking methods of analyses, standardizing solutions, calibrating pyrometers, etc., are given in Bureau of Standards Circular No. 25. Summaries of analyses of the standard samples and general information are given in the Supplement to Circular No. 25. These can be obtained free of charge upon application to the Bureau of Standards, Washington, D. C. Detailed certificates of analyses are sent under seperate cover to the same destination as the samples.

*Ordering.*—Orders should give both the number and name of the sample wanted. Example: No. 9c, steel, Bessemer, 0.2 C. No samples of smaller size than those listed are distributed.

*Terms and Shipping.*—(a) *Domestic.*—Samples may be paid for in advance with order. If the remittance does not accompany the order, all samples will be sent under Government frank by parcel post C. O. D. in the United States and its possessions. It is therefore important that firms with branch laboratories send remittance with the order if the laboratories can not receive C. O. D. packages. Both the central office and branch laboratory will be notified when shipment is made. No discounts are allowed on any orders.

(b) *Foreign*—All foreign shipments require prepayment. With the exception of Mexico and Canada, 20 cents postage must be added for every 300 grams of sample. Shipments intended for Mexico and Canada will be sent under Government frank, but not C. O. D.

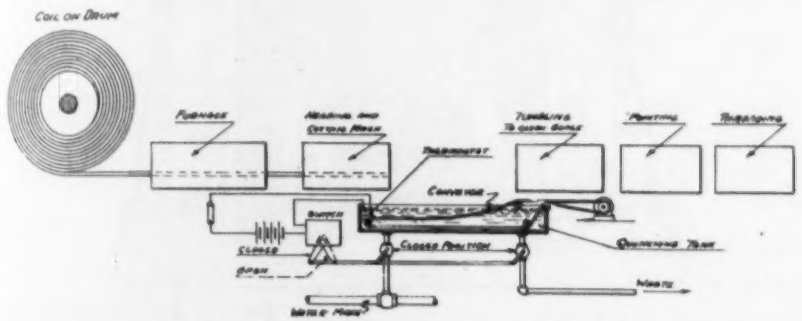
(c) *Money Orders, etc.,* should be payable to the Bureau of Standards.

# Reviews of Recent Patents

By NELSON LITTELL, Patent Attorney
475 Fifth Ave., New York City—Member of A. S. S. T.

**1,655,956, Method of Heat Treating and Heading Bolts, Chauncey A. Hoag, of Jackson, Michigan, Assignor, By Mesne Assignments, to Kelsey-Hayes Wheel Corp. of Detroit, a corporation of New York.**

This patent describes a method of heat treating and heading bolts in which the rod stock, in continuous form, is heated to a temperature in excess of that necessary for forging the bolt, cut and headed in the



cutting machine, quenched, tumbled to remove the scale and then pointed and threaded, the purpose of the excess heat being to secure a heat-treated effect to eliminate the appearance of cold working effects in the subsequent pointing and threading of the bolts.

**1,656,502, Process of Improving Aluminum Alloys, Wilhelm Sander, of Essen-Ruhr, Germany, Assignor to Th. Goldschmidt A. G., of Essen, Germany, a Firm.**

This patent describes a process of increasing the strength and elongation values of aluminum alloys by heat treatment of an alloy containing 97 per cent of aluminum, 1.3 per cent of magnesium silicide, 1.2 per cent of copper and 0.5 per cent of titanium. The method comprises quenching the alloy from a high and glowing temperature, aging at the ordinary temperature for a substantial length of time and thereafter aging at a temperature in the neighborhood of 145 degrees Cent.

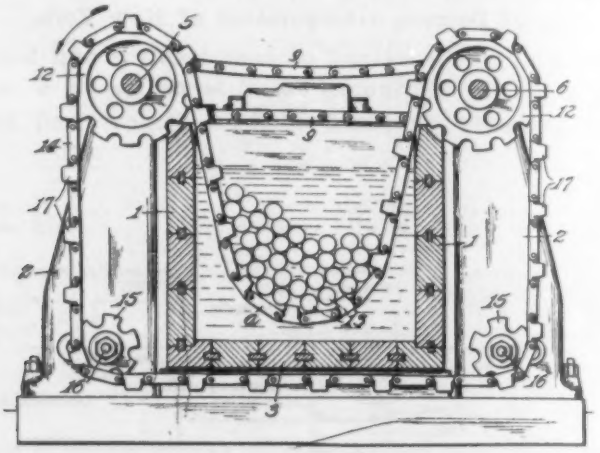
**1,656,535, Art of Making Malleable-Iron Castings, Harry A. Schwartz, of Cleveland Heights, Ohio, Assignor to National Malleable and Steel Castings Co. of Cleveland, a Corporation of Ohio.**

This invention relates to the production of malleable iron castings and is intended to reduce the period of annealing in the high temperature zone. Instead of treating the iron melted in the cupolas in a basic lined electric furnace, an acid lined electric furnace is used and the metal protected by a silica or other acid slag. After casting, the annealing process can be

completed in a much shorter time and the product is superior to that of the malleablized castings treated in basic lined electric furnaces.

**1,656,528, Pickling Apparatus, Joseph W. Millard, of Martins Ferry, Ohio.**

This patent describes an apparatus primarily for the pickling of butt and lap weld tubes for the purpose of removing and dislodging scale therefrom. In the drawings 1 indicates the tank for the pickling solution, columns 2 for supporting the shafts 5 and 6 are located at each side of the




tank 1 and over the sprockets 12 of the shafts 5 and 6 is a pair of endless chains 14 which dip into the tank 1 to provide a support for the tubes 13 to be pickled. The movement of the chain 14 over the sprockets 12 causes the projecting lugs 17 thereon to effect a rolling and tumbling action of the tubes 13 in the pickling solution to effectively dislodge the scale to be removed by the bath.

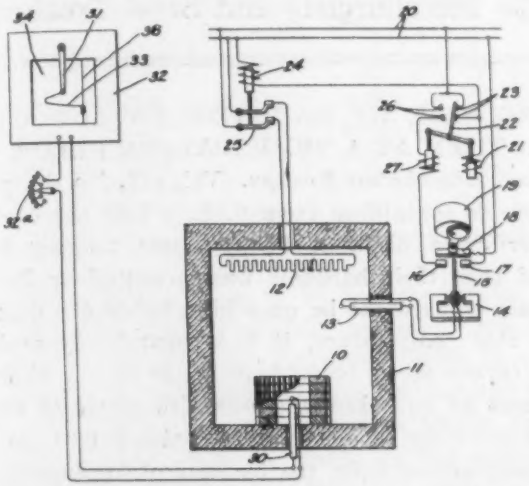
**1,656,695, and 1,656,696, Metal Alloy, George Clifton Deeter, of York, Pennsylvania.**

These patents relate to a scavenger and deoxidizing alloy for use as a fluxing agent in the melting down of certain metals, particularly red and yellow brasses and low lead bronzes. In the first patent the scavenger alloy consists of nickel 40 to 50 per cent, tin 3 to 10 per cent, phosphorus 0.30 to 1 per cent, manganese 1.50 to 5 per cent and copper in the amount necessary to form 100 per cent. In the second patent the alloy consists of copper 84 per cent, nickel 10 per cent, tin 5 per cent, manganese 0.75 per cent, phosphorus 0.25 per cent.

**1,658,682, Heat Treatment of Metals, Carl L. Ipsen, of Schenectady, New York, Assignor to General Electric Co., a Corporation of New York.**

This patent relates to the heat treatment of metals and to a means for controlling the temperature of the heat treating furnace. In the drawings 11 indicates the furnace chamber in which the stack of gears or other articles 10 are to be heat treated are placed. The temperature of the

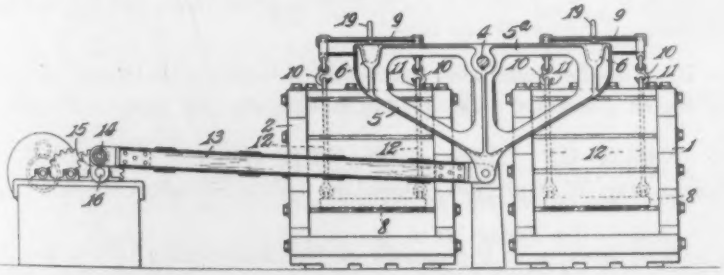
furnace is automatically maintained at the proper quenching temperature for the gears 10 by means of the pyrometer 13, connected to a galvanometer 14, in position to control the contacts of the pointer 15 with the contacts 16 and 17, which ultimately control the heat to the resistor 12 in the



furnace. A second pyrometer 30, in contact with the gears 10 undergoing treatment, may be used to indicate when the gears 10 have reached the temperature of the furnace.

1,656,693, **Pickling Apparatus, William J. Cook, of Wheeling, West Virginia.**

This patent describes a pickling apparatus which provides a pair of rocker members 5 provided with bearing-like pockets 6 for receiving the trunnions of a carrier for sheets to be pickled. The rocker members 5 are pivotally mounted on a rod 4 between two pickling tanks 1 and 2. The



sheets to be pickled, which are deposited edgewise on the rack 8, may be alternately raised and lowered in the tanks 1 and 2 by means of the motor, gears and levers 14, 15 and 16, to effect an agitation of the sheets during the pickling operation. As the sheets on the rack 8 are substantially balanced, a very small amount of power is necessary for effecting the alternate movement of the sheets.

# Abstracts of Technical Articles

## Brief Reviews of Foreign Publications of Interest To Metallurgists and Steel Treaters

ON THE INCREASE OF HARDNESS OF LOW CARBON STEELS BY QUENCHING THEM AT A TEMPERATURE BELOW THE $A_1$ POINT. By Yukio Yamada. *Kinzoku no Kenkyu.* Vol. III, No. 11, p. 537-538.

Low carbon steels containing from 0.01 to 0.09 per cent of carbon were quenched in water from different temperatures ranging from 100 to 650 degrees Cent., and then their hardness was measured by Rockwell's hardness tester. The increase of hardness by quenching below 400 degrees Cent. is very slight, but above that temperature, it is comparatively rapid, the maximum increase for these carbon steels being from 12 to 30. A figure shows the relation of the hardness of quenched and annealed steels to the percentages of carbon. Since the solubility of carbon at $A_1$ point is 0.04 per cent and rapidly decreases as the temperature falls, the increase of hardness just referred to is easily understood. The aging effect on the hardness of quenched steels was not observable. *Abstracted by Dr. Kotaro Honda, Japan.*

ON THE DENSITY OF SINGLE CRYSTALS OF IRON. By Seiji Kaya. *Kinzoku no Kenkyu,* Vol. IV, No. 2, p. 81-82.

The author measured the densities of single and polycrystals of iron having the same compositions in order to see whether the intercrystalline space in the case of polycrystals has an appreciable effect on the density. The result of five independent observations both for single crystals and polycrystals gives the following mean values:

| | | |
|---|---|---|
| Single crystal: | $7.8701 \pm 0.0003$, | 0 degrees Cent. (32 degrees Fahr.) |
| Polycrystal : | $7.8672 \pm 0.0007$, | 0 degrees Cent. (32 degrees Fahr.) |
| Difference : | 0.03 per cent | |

Thus it is to be concluded that the interspace between microcrystals is extremely small. *Abstracted by Dr. Kotaro Honda, Japan.*

THE WEAR OF DIES AND THE STEEL PROBLEM IN HOT STAMPING. By W. Spitzner, Dresden. *Maschinenbau,* October 7, 1926, p. 880 to 887.

This article deals with the causes of the destruction of screw-matrices and with the investigation of the qualification of some steels for this purpose.

Properties of the screw material used; hot-rolled, tensile strength 36 to 39 kilograms per square millimeter, yield point 25 to 29 kilograms per square millimeter, elongation 32 to 38 per cent, reduction of area 67 to 72 per cent.

Tempered material: tensile strength 46 to 52 kilograms per square millimeter, yield point 40 to 46 kilograms per square millimeter, elongation 6 to 11 per cent, reduction of area 62 to 65 per cent. The bolts were heated from 800 to 1100 degrees Cent. (1472 to 2012 degrees Fahr.) according to the diameter

of the bolt and to the shape of the screw head. Some of the die steels had the following chemical composition:

**Table I**

**Chemical Composition of Die Steels**

Per Cent

| | C | Mn | Si | P | S | Cr | Mo | W |
|---|---|---|---|---|---|---|---|---|
| A | 0.39 | 0.79 | 0.40 | 0.014 | 0.056 | | | |
| B | 1.25 | 0.129 | 0.305 | 0.010 | 0.003 | 0.225 | | 7.035 |
| Fl | 0.388 | 0.073 | 0.122 | 0.010 | 0.002 | 0.562 | | 7.035 |
| F | 0.630 | 0.127 | 0.212 | 0.020 | 0.003 | 0.667 | | 5.372 |
| G | 0.43 | — | 0.48 | — | — | 2.05 | 0.15 | 2.82 |

The matrices were quenched in oil or by a water stream according to the composition. The following table shows the hardening temperatures and the Brinell hardness on the surface of the matrices (Table II). When working, the dies are cooled with water to avoid too high heating and to wash away the scale. Destruction of the dies: the matrices grow useless by (1), the widening of the bore, (2), the formation of cracks on the surfaces and pressing in of them, (3), the wearing out of the edges and surfaces.

**Table II**

| | Hardening Temperature | Tempering Temperature | Brinell Hardness |
|---|---|---|---|
| A | 970, water jet | | 506-588 |
| B | 800, water jet | | 313-557 |
| Fl | 1000, oil | 500-520 degrees Cent., 120min. | 373-460 |
| F | 1000, oil | | 418-478 |
| | 950, oil | 510 degrees Cent., 90min. | 337-386 |
| | 950, oil | | 348-453 |
| G | 950, oil | 540 degrees Cent., 105min. | 360-400 |
| | 950, oil | 420-500 degrees Cent., 90min. | 368-416. |

The causes of the destruction are the stamping pressure, the friction and the press temperatures.

The author gives stamping pressures for screws of different size, and tells how it increases with growing diameter of the shaft and with increasing size and shape of the head. Pre-upsetting is of great advantage for the die. The pressures are further dependent on the temperature of the stamped pieces and on the thickness of the seam. The widening of the bore is the result of the pressure acting in the bore radially outwards. The gradual give of the bore may be traced back to fatigue phenomena of the material.

The friction produces only a little of the wear. The pressing temperatures cause, above all, rendering the dies useless. To avoid the heating, the dies are cooled, but the formation of cracks is inevitable. Temperature measurements showed that the temperature of an uncooled matrix 2 to 3 millimeters

under the surface increases rapidly with every pressure and soon reaches an amount high enough to soften the die. In cooled dies an equilibrium state is reached after some time. The temperature of the die depends upon the temperatures of the bolt, upon its thickness and upon the velocity of pressing, further upon the temperature and the quantity of the cooling water. Nevertheless the temperature of cooled dies may be from 150 to 300 degrees Cent. (302 to 572 degrees Fahr.) and soften the edges. By cooling, the temperature of the highest layers oscillates considerably up and down and by this the surface becomes cracked. This effect is increased by short stops in the working. The effect of the pressing temperatures is increased with increased working speed; further the disproportionate temperatures are unfavorable to the stamped pieces and the distribution of the cooling water. The durability of the die is favorably influenced by careful machining of the die, exact heat treatment, suitable measurement of the die, uniform stamping material, uniform temperature of the stamped pieces, avoidance of too high pressures and too violent shocks, suitable establishment of the cooling and the temperature of the pressed pieces.

*Properties of die steel:* These are high tensile strength, great resistance against endurance stresses, tough structure, high hardness on the working planes, high tensile strength and hardness at elevated temperatures 300 to 500 degrees Cent. (572 to 932 degrees Fahr.).

Carbon steels are unsuitable for die steels; only a steel containing 0.30 to 0.50 per cent carbon and a higher percentage of manganese may be used; chromium (4 per cent) and tungsten steels have good properties. Very good results were obtained with the steels F1, F and G, hardened from 900 to 1000 degrees Cent. (1652 to 1832 degrees Fahr.) in oil and tempered at 400 to 550 degrees Cent. (752 to 1022 degrees Fahr.) during 30 to 120 minutes. The suitable Brinell hardnesses are 350 to 450. Tungsten steels are tough and heat resistant. An increasing of the amount of tungsten up to 10 to 12 per cent (about 0.35 per cent carbon) further improves the qualities.

Steels of the composition F and G with 0.15 to 0.50 per cent vanadium also give good results. Steels with higher amounts of tungsten and a lower carbon content are quenched from 1100 to 1200 degrees Cent. (2012 to 2192 degrees Fahr.) in oil and tempered at 600 degrees Cent. (1112 degrees Fahr.); the air hardening steel may also be used.

Chromium-nickel and chromium-tungsten, molybdenum-nickel steels are also used. A sample of the latter even in the unhardened state gave very good results, 350 to 370 Brinell. *Abstracted by Dr. Hans Pollack, Germany.*

ON THE MAGNETOSTRICTION OF SINGLE CRYSTALS OF IRON. By Kotarô Honda and Yosio Mashiyama. *Kinzoku no Kenkyu*, vol. IV, No. 2.

With the same ellipsoid used in a previously reported investigation, No. 1 the longitudinal and transverse effects of magnetic elongation were observed for different orientations of the ellipsoids and for different strengths of the field. In the direction of the tetragonal axis, the longitudinal effect of magnetic elongation is positive for all fields, and in the direction of the trigonal axis, it is always negative; in other directions the magnetic elongation is positive

in weak fields and negative in strong fields. The transverse effect is just the reverse of the longitudinal one. The magnetic expansion in ordinary iron consisting of microcrystals is a differential effect of these expansions and contractions above referred to, the crystal axes being distributed at random. The smallness of the magnetic expansion of ordinary iron as compared with that of the single crystal, as well as the course of the expansion-curve are well understood from the above view.

Under a constant field, the variation of the longitudinal and transverse effects is periodical with respect to the orientation of the ellipsoids, the periods being 90, 180 and 60 degrees for planes (100), (110) and (111) respectively, as in the case of magnetization. *Abstracted by Dr. Kotaro Honda, Japan.*

A FURTHER STUDY OF THE DISTRIBUTION OF HARDNESS IN QUENCHED CARBON STEELS. By Tuton Kasé. *Kinzoku no Kenkyu.* Vol. 3, No. 8, page 377-384.

In order to confirm the results of experiments made by K. Honda and S. Idei (*Science Reports.* Vol. 9, 1920, 491), 6 years ago, the quenching experiments were made on cubes of 3 centimeters on each side, or short cylinders of 3 centimeters in diameter and height, made of carbon steels containing 0.3-1.48 per cent of carbon. The hardness was measured by a Shore scleroscope. The results of observations are summarized as follows:—

(1) In a mild quenching, the outside portion of the cube or the cylinder is harder than its central portion; for example, 0.3-0.6 per cent carbon steels quenched from 900 degrees Cent. in oil. In a medium quenching, the hardness is everywhere the same; for example, 0.3-0.6 per cent carbon steels quenched from 1000-1100 degrees Cent. in oil. In a severe quenching, the outside portion is softer than the central; for example, 0.9-1.5 per cent carbon steels quenched from 900-1000 degrees Cent. in water.

Since the hardnesses of austenite ($H_a$), martensite ($H_m$) and troostite ($H_p$) are of the following order:—

$$H_a < H_p < H_m,$$

the first two cases above described require no further explanation; in the third case of severe quenching, the outside portion where the cooling is too rapid, contains, besides martensite, untransformed austenite, while the central portion consists wholly of martensite, or contains a small quantity of retained austenite. Hence the hardness of the outside portion is less than the central portion.

(2) Quenched steels all have a slight aging effect; that is, the hardness of steels quenched in water or oil from 800-1100 degrees Cent. increases at first comparatively rapidly and then very slowly. This is attributed to the differential effect of a slow tempering of martensite and a very slow change of retained austenite into martensite at room temperature. In some cases, during the first 5 to 6 hours, the contraction due to the tempering of martensite is observed and afterwards a slow increase due to the change of retained austenite into martensite is observed.

(3) The tempering at higher temperature than the room temperature accelerates the aging of the quenched steels.

(4) Quenching cracks take place during too severe quenching, where the

central portion is considerably harder than the outside portion. Since the specific volumes of austenite $V_a$, martensite $V_m$, and troostite $V_p$ are of the following order:

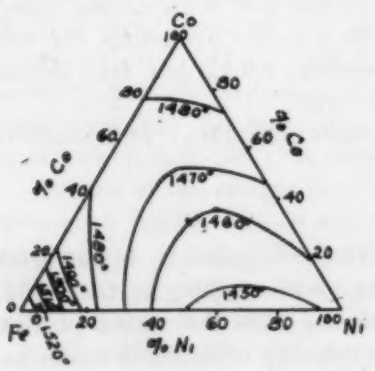
$$V_a < V_p < V_m,$$

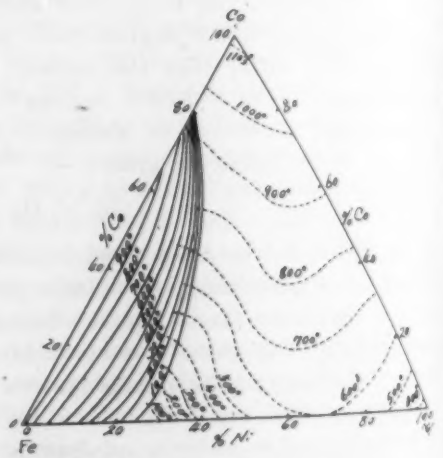
it is evident that in the case of the severe quenching, the outside portion contains more retained austenite than the central portion, and hence the former portion undergoes from the latter a great tension; this stress, if it is sufficiently large, will cause the cracking of the material.

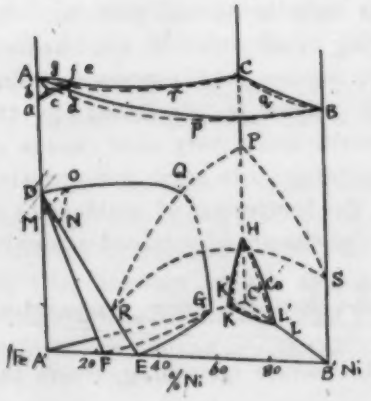
(5) By immersing quenched steels in liquid air, its hardness increases more or less; this is due to the transformation of retained austenite into martensite. *Abstracted by Dr. Kotaro Honda, Japan.*

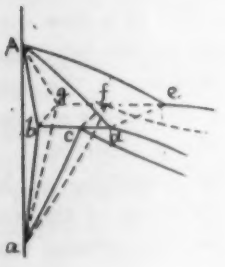
ON THE EQUILIBRIUM DIAGRAM OF THE SYSTEM IRON-NICKEL-COBALT. By Tuton Kase. *Kinzoku no Kenkyû*, vol. III, No. 12, p. 539-555.

The equilibrium diagram of this ternary system was investigated by the author by means of thermal, magnetic and dilatometric analyses. The hardness measurement and a microscopic investigation were also availed of. The equilibrium diagram of three binaries composed of two of the three ferromagnetic metals have already been completed by H. Masumoto and the author. The results of the investigation are graphically given in the figures below:—The magnetic or $A_2$ lines in the system, there being no change of phase, are shown in dotted lines (OMN and PORS in this figure).



# THE ENGINEERING INDEX

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Arrangements have been made with The American Society of Mechanical Engineers whereby the American Society for Steel Treating will be furnished each month with a specially prepared section of The Engineering Index. It is to include items descriptive of articles appearing in the current issues of the world's engineering and scientific press of particular interest to members of the American Society for Steel Treating. These items will be selected from the copy prepared for the annual volume of the Index published by the A. S. M. E.

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## AIR HEATERS

GAS CIRCULATION. The Circulation in Air Heaters (Die Gasbewegung im Winderhitzer), R. Kalenberg. Stahl u. Eisen, vol. 48, no. 3, Jan. 19, 1928, pp. 65-71, 7 figs. With usual draft measurements, it is not possible to measure air lift and resistance separately; method is described for measuring these two factors separately; influence of resistance on efficiency of Cowper stoves; quantitative investigation of results show that friction losses predominate only in grid, otherwise impact losses predominate.

## ALLOYS

CORROSION-RESISTANT. Corrosion Resistant Alloys. Mech. World, vol. 83, no. 2141, Jan. 13, 1928, pp. 30-31. Discusses principal external factors which affect corrosive attack including dissolved oxygen and surface films. (Continuation of serial.)

HIGH STEAM PRESSURES, FOR. What Is the Limiting Temperature in Central-Station Operation? V. T. Malcolm. Mech. Eng., vol. 50, no. 2, Feb. 1928, pp. 137-142, 16 figs. As result of his investigations author concludes that design of equipment must be based upon strength of metals at operating temperatures, over long periods of time, and that other properties such as thermal expansion, thermal conductivity, chemical stability, resistance to wear and abrasion, etc. must receive greater attention than in present engineering practice; includes ten charts giving data on certain alloys that author considers safe for operation at 1000 deg. Fahr. Bibliography.

MOLTEN, HEAT OF MIXTURE. On the Heat of Mixture in Molten Metals, M. Kawakami. Tohoku Imperial University—Sci. Reports, vol. 16, no. 8, Dec. 1927, pp. 915-935, 21 figs. Head of mixture, in case of binary alloys of fusible metals, was determined with 3 different calorimeters; in case of alloys having no intermetallic compound, this heat is negative, with exception of some bismuth alloys; for alloys having one or more intermetallic compound, heat of mixture is positive and very large as compared with that in last case; this fact confirms view that intermetallic compound existing in solid phase does not decompose into its components during melting, but exists as such in liquid phase. (In English.)

NON-OXIDIZING. Water Supply Pipes for Cooling Furnace Electrodes (L'emploi des tuyaux "Resisto" pour le réfroidissement des pinces d'electrodes de fours électriques). Génie Civil, vol. 91, no. 16, Oct. 15, 1927, p. 388, 1 fig. Asbestos-sheathed flexible pipes made of non-oxidizing alloy "Resisto" (composition not stated) are used by Societe des Electrodes de Savoie in order to carry cooling water to terminals of Soderberg continuous, self-baking electrodes in electric furnaces; this alloy is claimed to withstand temperatures up to 400 deg. cent., mechanical loads up to 5700 lb. per sq. in.

OIL-DRILLING EQUIPMENT. The Use of Hard Facing Metals in California Oil Drilling, E. G. Fulton. Oil Field Eng., vol. 3, no. 1, Jan. 1928, pp. 43-52, 10 figs. General adoption by most progressive operators, of hard metals for facing cutting edges of all drilling tools; metal most largely used for this purpose in California fields is ternary alloy of chromium, cobalt and tungsten.

QUANTITATIVE ANALYSIS. New General Method of Quantitative Analysis of an Alloy (Nouvelle méthode géneral d'analyse quantitative d'un alliage), O. Macchia. Fonderie Moderne, vol. 21, Dec. 25, 1927, pp.

Those members who are making a practice of clipping items for filing in their own filing system may obtain extra copies of the Engineering Index pages gratis by addressing their request to the society headquarters, whereby their names will be placed on a mailing list to receive extra copies regularly.

507-510. Presents method of analysis which allows quantitative determination immediately, of metals which compose alloys without any preliminary analysis, when metals are Sn, Sb, Ni, Co, Cd, Cu, Zn, Mg, Pb, Al, Fe, Bi, Mn.; this method does away with many acids.

## ALLOY STEELS

AIR CRAFT. Alloy and Stainless Steels, J. Hopcraft. Royal Aeronautical Soc.—Jl., vol. 32, no. 205, Jan. 1928, pp. 69-76. Aircraft steels and care required in manufacture, from melting furnace to finished rolled bar; high properties of no use if defects and lack of homogeneity occur in sheet and bar; main advantages of electric furnace; precautions; steel structure and composition; treatment to obtain wear-resisting hardness, combined with resistance to shock (toughnese) so desired by aircraft constructor; carbon steels used in aircraft; case-hardening, and alloy steels; stainless steels; welding, soldering, brazing.

ANALYSIS. Potentiometric Determination of the Hardening Elements in Special Steels (Die Potentiometrische Analyse der Stahlhaertungsmetalle und Spezialstaehle), E. Zintl and P. Zaimis. Zeit. fuer angewandte Chemie, vol. 40, no. 44, Nov. 3, 1927, pp. 1286-1291, 3 figs. Determination of chromium and vanadium in presence of iron. See brief translated abstract in Chem. & Industry, vol. 46, no. 51, Dec. 23, 1927, p. 939.

BEARINGS. Alloy Bearings Applied to Trains, F. C. Langenberg and C. McKnight. Iron Age, vol. 121, no. 2, Jan. 12, 1928, pp. 130-131, 3 figs. Nickel-molybdenum steel in low-carbon compositions satisfactorily used for piston pins, differential gears, ring gears, steering knuckle pins; possibility of obtaining fine core and hard case after single quench; heat-treating applicable for high temperatures; alloys in scrap recoverable; chart showing physical properties of core of case-hardening nickel-molybdenum steel, single treatment; table of properties of heat treated specimens tested at 74,600 lb. per sq. in. at 1000 deg. Fahr.

DEVELOPMENTS. Alloy Steels. Iron & Coal Trades Rev., vol. 116, no. 3123, Jan. 6, 1928, p. 11. Most marked characteristic of nickel steel was wide range of composition for which alloys of industrial usefulness had been found to exist; nickel-chrominum steels could be made more cheaply than plain nickel steels of same strength and ductility; silicon, chromium-vanadium, tungsten-chromium, tungsten-chromium-vanadium and heat resisting steels.

ENGINE EXHAUST VALVES. Valve Steels (Les developements les plus recents des aciers speciaux), H. Drouot. Technique Moderne, vol. 19, no. 19, Oct. 1, 1927, pp. 603-604. Valves in explosion engines have to satisfy certain conditions which are particularly strenuous in case of exhaust valves; metal must be of sufficient hardness when hot so as not to be distorted; it must not be brittle; number of steels have been tried out, including high-speed steels with large content of chromium and tungsten; stainless steels; austenitic steels with high content of nickel and chromium and additions of manganese and tungsten; high-carbon cobalt-chromium steels and silchrome steels (silicon-chromium-carbon) See brief translated abstract in Mech. Eng., vol. 49, no. 12, Dec. 1927, p. 1352.

HEAT RESISTING. Heat Resisting and Non-Corrodible Steels, S. A. Main. Fuel, vol. 7, no. 1, Jan. 1928, pp. 4020, 17 figs. Account of progress which has taken place lately including development and practical application of heat resisting and non-corroding steels; deals particularly with products resulting from research carried out by author's firm, Hadfields, Ltd., Sheffield, England. Reprinted from Jl. of Instn. of Aeronautical Engrs., Aug. 1927.

INDUSTRY, 1927. Recession in Alloy Steel Output in 1927 is Slight. Iron Trade Rev., vol. 82, no. 1, Jan. 5, 1927, pp. 42-43. Alloy steels are being increasingly employed; noncorroding chromium steel improved by addition of fairly high amount of nickel; airplane fuselage made of tubing; heaviest consumer of alloy steel is automotive industry; distribution in tons of output of alloy steel in 1927; distribution by percentage of alloy steel in 1927; alloy steel output in 1927 by form.

PERMANENT MAGNETS. Permanent Magnet Steel. Foundry Trade Jl., vol. 38, no. 595, Jan. 12, 1928, p. 24. Steel must be capable of being melted without any tendency for any of constituents to separate out on freezing; it must be easily rolled so that minimum of heating is necessary; steel must have high hysteresis coefficient to give necessary retentivity; it must be capable of being made extremely hard; it must be absolutely homogeneous; principal magnetic properties; tungsten magnet steel has usually better magnetic properties than chromium magnet steel.

## ALUMINUM

AUSTRIAN STANDARDS. New Austrian Standard for Aluminum (Die neuen oesterreichischen Normen fuer Aluminium). Zeit. fuer die gesamte Giessereipraxis (Metall), vol. 49, no. 1, Jan. 1, 1928, pp. 2-4. New Austrian standards correspond closely to German standards; gives new specifications for bronze and bearing metals.

MELTING. Melting Pot and Crucible Furnaces in the Aluminum Industry, E. R. Thews. Metal Industry (Lond.), vol. 31, no. 26, Dec. 30, 1927, pp. 597-599, 1 fig. Great hope is being placed upon suitability of electric furnaces, but it appears that for time being practically satisfactory results can only be obtained with fuel-fired furnaces, that is to say, with reverberatory, crucible, and melting-pot furnace; disadvantage of latter is strong affinity of molten aluminum for iron, which causes rapid wear of pots and inevitable contamination of aluminum with iron; results of corrosion experiments; corrosion of pot walls. (To be continued.)

OVERHEAD LINES. Aluminum Overhead Lines. Metal Industry (Lond.), vol. 31, no. 26, Dec. 30, 1927, p. 603. Review of booklet issued by British Aluminum Co.; bears testimony to ability of aluminum and steel-cored aluminum conductors to give satisfactory service under most unfavorable and stringent atmospheric conditions, varying from extreme colds of northern winters to humid atmosphere of tropical India.

OXIDIZABILITY. Measurement of the Oxidizability of Aluminum and Its Industrial Alloys After Activation by Mercuric Chloride (Mesure de l'oxidabilite de l'aluminium et des ses alliages industriels apres activation par le bichlorure de mercure), C. Quillard. Académie des Sciences—Comptes Rendus, vol. 185, no. 19, Nov. 7, 1927, pp. 953-955, 1 fig. Calorimetric method for determination of oxidizability of activated aluminum and its alloys by air in terms of maximum rise in

temperature as shown by time-temperature curves. See brief translated abstract in Chem. & Industry, vol. 46, no. 51, Dec. 23, 1927, p. 940.

## ALUMINUM ALLOYS

AIRSHIP CONSTRUCTION. Giant Airships Use Aluminum Alloy Construction. Metal Industry, (N. Y.), vol. 26, no. 1, Jan. 1928, p. 18, 2 figs. Framework of giant Zeppelin being built in Germany is of structural duralumin, 17 S metal or similar alloy; about 4 per cent copper, 0.5 per cent manganese, 0.5 per cent magnesium, balance aluminum.

ALUMINUM-COPPER. Segregation of Aluminum-Copper Alloys. Foundry Trade Jl., vol. 37, no. 593, Dec. 29, 1927, p. 224, 1 fig. Review of paper by W. Claus and B. Dango, published in Zeit. fuer Metallkunde, no. 9, 1927, p. 358, describing experiments with American alloy containing 8 per cent copper, as authors were of opinion that segregation might be responsible for failure in mechanical strength which occurs often with this alloy.

ALUMINUM-ZINC. Refinement of Constructral Montegal (Zur Theorie der Veredelung von Constructal und Montegal), W. Guertler. Zeit. fuer Metallkunde, vol. 19, no. 12, Dec. 1927, pp. 488-491, 6 figs. Comparison between theory of hardening of steel and theories of refining of duralumin; describes attempts to improve quality of aluminum by additions of zinc; author's investigation proves value of theoretical principles in discovery of new refining media.

AUTOMOBILE CASTINGS. Light Aluminum Alloy Castings in Motor Car Construction, E. C. Hill. Metal Industry (Lond.), vol. 32, no. 2, Jan. 13, 1928, pp. 50-54, 4 figs. Term, light alloys, is applied broadly to whole of aluminum group, and extends sometimes to that metal itself; such materials are extensively employed as pressure die castings, gravity die castings and sand castings, in automobile construction; heat conductivity of aluminum pistons favors self cooling and thus helps to eliminate slapping; whole subject is detailed.

## ALUMINUM BRONZE

CASTING AND WORKING. Aluminum Bronze, W. J. Reardon. Metal Industry (N. Y.), vol. 26, no. 1, Jan. 1928, p. 6. Progress in casting and working of this alloy; American developments; special properties and uses; future possibilities.

## AUTOMOTIVE INDUSTRY

CONSTRUCTION MATERIALS. Materials Exhibited at the Berlin Engineering Materials Exhibition of Interest to the Automobile and Aircraft Industry (Was bot die Werkstoffschau dem Automobil- und Flugzeug-Konstrukteur?), W. Claus and F. Goederitz. Motorwagen, vol. 30, no. 34, Dec. 10, 1927, pp. 713-717, 12 figs. Discusses exhibits of iron and steel, nonferrous metals and insulating materials with examples of their application in automobile and airplane parts; special and stainless steel; welding applications; nonferrous exhibits included bronze bearings and carburetor parts, nickel plate, magnesium, pure aluminum, high-grade aluminum alloys and aluminum castings.

## BEARING METALS

WHITE METAL BEARINGS. Automobile Engr., vol. 18, no. 237, Jan. 1928, pp. 25-26, 1 fig. Informative investigation regarding adhesion between white metal and bearing shells; thorough cleaning and tinning absolutely essential for all types of surfaces and materials; cast iron and white metal; adhesion between white metal and cast iron assisted by natural roughness, and porosity of surface; efficiency of joint of 50 per cent or more obtained between white metal and gun-metal; with mild-steel test pieces, good adhesion of white metal on machined surface fairly easily obtained; sand blasting and pickling; design of bearing bushes; more extensive use made of pressed steel or machined tubular-steel bearing shells.

## BRASS

CASTING AND ROLLING. Brass Rolling Mill Progress, W. J. Pettis. Metal Industry, (N. Y.), vol. 26, no. 1, Jan. 1928, pp. 4-5. Review of quarter of century in brass casting shop and rolling mill; electric melting.

CASTINGS. The Effect of Waste on the Cost of Manufacturing Plumbers' Brass Foundry Castings, A. Handerson. Metal Industry (Lond.), vol. 31, no. 16, Oct. 21, 1927, pp. 368-369. How waste arises, and its incidence on cost of finished article; waste on white-metal castings.

MACHINING PROPERTIES. The Machining Properties of Brass Rod and Castings. Brass World, vol. 24, no. 1, Jan. 1928, p. 10. After long series of experiments it has been found that most easily machined brass is that containing approximately 60 per cent copper and 1.5 per cent lead which has same structure as alloy containing exactly 60/40 respectively; therefore, every care should be taken to obtain alloy of this composition with none or little of other metals present.

## CASE HARDENING

DIFFUSION. Case-Hardening of Metals by Diffusion. Diffusion of Tungsten in Iron (Die Oberflaechenveredelung der Metalle durch Diffusion. Die Diffusion von Wolfram in Eisen und die Resistenzgrenzen der Eisen—Wolframlegierungen), G. Grube and K. Schneider. Zeit. fuer Anorganische u. Allgemeine Chemie, vol. 168, no. 1, Nov. 21, 1927, pp. 17-30, 4 figs. Results of experimental research, done in laboratory of physical chemistry of Stuttgart Institute of Technology; describes heat treatment of iron in hydrogen medium in presence of tungsten; calculation of diffusion coefficient; determination of limits of chemical resistance.

NITRATION. Nitralloy and the Nitriding Process, H. A. DeFries. Machy. (Lond.), vol. 31, no. 796, Jan. 12, 1928, pp. 478-479. Special alloy steels which can be surface-hardened by being subjected to action of ammonia gas while material is heated to temperature of approximately 875 deg. Fahr. without subsequent quenching; remarkable resistance to metal-to-metal wear; excellent forging properties; machined satisfactorily in both annealed and heat treated conditions; composition and uses of nitralloy; heat treatment of nitralloy previous to nitriding; nitriding process and equipment used for it; depth and hardness of case.

NITRATION. Surface Hardening by Nitrogen. Iron & Steel of Can., vol. 11, no. 1,

Jan. 1928, pp. 19-21. Invention of Dr. Fry, of Research Laboratories of Friedrich Krupp, of Essen; process consists of subjecting parts to be hardened to action of ammonia gas at temperature of approximately 500 deg. Cent. for period of time varying from 40 to 120 hours.

## CAST IRON

ACID-RESISTING. Acid - and Alkali - Resisting Cast Iron (Saeure- und alkalifestes Gusseisen), H. G. Haase. Stahl u. Eisen, vol. 47, no. 50, Dec. 15, 1927, pp. 2112-2117, 10 figs. Experiments on anti-corrosive, protective effect of carbon, silicon, manganese, phosphorus, sulphur, nickel and casting skin on solubility of cast iron in acids and alkalis of various concentrations and temperatures; suggests quantitative chemical composition of most resistant cast iron.

ALUMINUM IN. Aluminum Cast Irons, A. B. Everest. Foundry Trade Jl., vol. 37, no. 592, Dec. 22, 1927, pp. 208-210, 1 fig. Discusses gray cast iron formed by addition of aluminum to low-silicon irons; mechanical tests were made on alloys formed by adding aluminum to American washed iron; results indicate that at moment there is no definite future for aluminum cast iron for normal purposes; no special properties have been shown which cannot be obtained by other simpler and better methods of treating cast iron.

FLUIDITY. Test Bars to Establish the Fluidity Qualities of Cast Iron, C. Curry. Foundry Trade Jl., vol. 36, no. 580, Sept. 29, 1927, pp. 283-286, 11 figs. Fluidity is defined as aptitude of liquid in given condition to fill a mold prepared under determined conditions; review of tests carried out with view to studying factors involved; fluidity test applied to nonferrous work.

GRAPHITIZATION. The Graphitization of Cast Iron (Die Spongiose des Gusseisens), R. Stumper. Korrosion und Metallschutz, vol. 3, no. 12, Dec. 1927, pp. 265-268, 4 figs. Author's investigation convinces him that theory of Bauer and Wetzel is correct, namely, that graphitization is a phenomenon which occurs simultaneously with corrosion of cast iron.

HIGH-SILICON. Determines Properties of High Silicon Irons, R. H. Hobrock. Foundry, vol. 56, no. 2, Jan. 15, 1928, pp. 55-59, 12 figs. To examine effects of silicon content on physical properties, four different types of test bars were made which included two standard arbitration bars, and one each of chill bar, step bar and shrinkage bar; from results obtained author concludes that introduction of large amounts of silicon into gray iron decreases its strength greatly.

IMPROVEMENTS. Exhibits of Cast Iron at the Berlin Engineering Materials Show (Das Gusseisen auf der Werkstoffschau), Lischka. Giesserei, vol. 15, no. 2, Jan. 13, 1928, pp. 33-39, 22 figs. Description of section devoted to cast iron, including machinery and machine tool castings, railway castings, heat resisting cast iron, chilled castings, cast iron with special magnetic properties, art castings, etc.

MAURER DIAGRAM. The Influence of Cooling Rate on Maurer Diagram for Cast Iron. Foundry Trade Jl., vol. 37, no. 593, Dec. 29, 1927, pp. 222-224, 4 figs. Maurer diagram demonstrates relationship between structure of cast iron and silicon and total carbon contents at ordinary cooling rate; results of experiments made by E. Maurer and P. Holtzhausen (see Stahl u. Eisen, nos. 43 and 47, 1927, pp. 1805 and 1977) showing how lines of diagram are modified by adopting various cooling rates.

MOLTEN. Measurement of Temperature of Liquid Cast Iron and Steel (La mesure de la temperature de la fonte et de l'acier liquides), M. Wenzl and F. Morawe. Fonderie Moderne, vol. 21, Sept. 25, 1927, pp. 369-373, 4 figs. Experiments were made at Sterkrade Works in Germany showing operative results of optical and thermoelectrical methods; presents number of tables showing results obtained. See translated abstract in Foundry, vol. 56, no. 2, Jan. 14, 1928, p. 73.

NICKEL AND CHROMIUM IN. Alloy Cast Irons. Metallurgist (Supp. to Engineer), Dec. 30, 1927, pp. 179-180. Review of recent investigations on influence of nickel and chromium in cast iron.

NICKEL AND CHROMIUM IN. The Practical and Economic Value of Nickel and Chromium in Gray Cast Iron, D. M. Houston. Int. Nickel Co.—Bul., no. 205, 8 pp., 12 figs. Fifth of series of technical articles on nickel cast iron; shows how effects of nickel and chromium may be utilized in practical manner by foundries in producing gray iron castings of substantially improved properties at minimum cost; industrial applications of nickel-chromium iron; use of nickel and chromium in automobile cylinders.

NICKEL IN. Effects of Nickel on the Machinability of Cast Iron. West. Machy. Wld., vol. 18, no. 12, Dec. 1927, pp. 591-592, 2 figs. Brief article with purpose of examining difficulties encountered in machining gray cast iron, and by means of metallurgical laws, microscope and chemical analysis pointing out causes for some of these difficulties; composition of gray cast iron; effect of combined carbon; hard spots and remedy; high silicon content and slow cooling promote internal shrinks; nickel in gray iron supplements silicon without inducing internal shrinking; nickel makes pre-annealing unnecessary; hardening and toughening effect on matrix will increase tool resistance.

PEARLITIC. Castings of High Resistance (Pearlitic Cast Iron) [Les fontes à resistance elevée (fontes perlitiques)], A. Le Thomas. Revue Industrielle, vol. 58, no. 2222, Jan. 1928, pp. 16-20, 6 figs. Increase in mechanical properties of high resistance cast iron, methods of making chemical and metallographic tests; various methods of making high resistance castings, viz; Lang, Emmel, Schuez are given; evolution of cast iron testing.

PROPERTIES. The Mechanical Properties of Gray Cast Iron In Relation to Structure and Treatment (Die mechanischen Eigenschaften des Graugusses in Abhaengigkeit von Gefuege und Behandlung), K. V. Kerpeley. Giesserei-Zeitung, vol. 25, no. 2, Jan. 15, 1928, pp. 37-49, 35 figs. Influence of cross-section on structure; influence of cooling velocities; evaluation of investigation of Bolton, Rother, Oberhoffer, Piwowarsky, Wuest, Hanemann, etc.; influence of different alloying elements on strength; influence of pouring temperature; annealing; superheated cast iron; investigation of Piwowarsky and Ker-

peley; critical discussion of different production methods for high grade cast iron.

## CUPOLAS

CONTROL. Control of Cupolas (Contrôle des cubilots), H. Carra and R. Fric. Chaleur & Industrie, vol. 8, no. 92, Dec. 1927, pp. 673-678, 2 figs. Discusses heat radiation, specific heat of gases, measurement of gas, pressure, analysis of gas, CO and $CO_2$ and amount of air necessary for combustion, relation between real and calculated percentages of CO and $CO_2$. (To be continued.)

DESIGN. Cupola Design (Kupolofenkonstruktion), R. Thews. Giesserei Zeitung, vol. 24, no. 24, Dec. 15, 1927, pp. 686-688. Aspects of design; relation between diameter and charge; height of furnace; number, size, and arrangement of tuyere levels; dimensioning of air pipes and windboxes; practical suggestions.

HISTORY OF. The History of the Foundry Cupola, J. E. Hurst. Eng., vol. 124, no. 3233, Dec. 30, 1927, pp. 830-831, 4 figs. Review of developments; introduction of cupola furnace, for remelting of iron for foundry purposes, was of a more or less gradual nature, and probably originated in England with traveling tinkers; broadly speaking Wilkinson was no doubt the first individual to perceive necessity for a smaller and more manageable unit than the blast furnace in meeting demands of organized foundry production.

OPERATION. Cupola Operation Requires Skill. Foundry, vol. 56, no. 2, Jan. 15, 1928, pp. 69-70. Gives information gained by actual contact during 20-year period on preparing and operating foundry cupola.

STEEL-SCRAP MELTING. Cupola Melting of Steel Affected by Coke Properties, J. T. MacKenzie. Foundry, vol. 56, no. 1, Jan. 1, 1928, pp. 15-18, 1 fig. Deals with total carbon absorbed by steel scrap when melted with various cokes of unusual collection, well representative and containing extremes likely to be encountered; cupola used was manufactured by Whiting Corp., Harvey, Ill., with 27-in. shell; it is assumed that extent of carburization depends on purity and structure of coke; for carburization, coke should not be either extremely dense or extremely porous; neither too hard nor too soft, too heavy nor too light.

STEEL-SCRAP MELTING. Cupola Melting with Special Reference to Value of Steel Scrap in Cupola Mixtures, W. Dennison. Foundry Trade Jl., vol. 37, no. 593, pp. 225-226, 5 figs. Writer claims, although term "semi-steel" is justifiably derided by metallurgists, that use of steel scrap in a cupola mixture has a beneficial influence on physical properties of resultant metal even when chemical composition gives no indication of such improvement; percentage of steel used to obtain best results will vary from 5 per cent for lightest of castings to 40 per cent for heaviest.

## CYLINDERS

AUTOMOBILE, CASTING. Aluminum Cylinder Blocks Cast in Permanent Molds, J. A. Lucas. Am. Mach., vol. 68, no. 4, Jan. 26, 1928, pp. 173-174, 6 figs. Method used in Lancia plant for casting cylinder blocks around cylinder sleeves and other inserts; have iron sleeves cast into aluminum block by unusual process that involves use of permanent metal molds and approaches die casting; oiling tubes welded into complete unit and placed in mold; sleeves rough bored, turned, then sand blasted and copper plated before being set in molds; cores located accurately by dowels.

NONFERROUS METALS. The General Aspects of Die-Casting, T. P. Russell. Metal Industry (Lond.), vol. 32, nos. 1 and 2, Jan. 6 and 13, 1928, pp. 5-7 and 57-59. Discusses history and future prospects of die-casting industry, with special reference to nonferrous die-casting; such processes have of late years made marked progress and are among those most favored by metal founders for machine parts and small casting. Paper read originally before Sheffield Met. Assn., but revised for this journal.

## DURALUMIN

AIRPLANE MANUFACTURE. Duralumin —Defects and Failures, W. Nelson. Nat. Advisory Committee for Aeronautics—Tech. Memorandum, no. 443, Dec. 1927, 13 pp., 4 figs. Defects produced during manufacture of raw material and during fabrication of material into parts; cases where strains on duralumin are accompanied by imperfections in surface as result of contact with some foreign substance; raw-material inspections; buckles appear in sheet stock; occluded gas forms blisters; blisters resulting from normal heat treatment and those resulting from overheating metal; roll marks destroy uniformity; buckles can be prevented; proper heat treating essential.

PROPERTIES AND TREATMENT. "Duralumin," L. Aitchison. Metal Industry (Lond.), vol. 31, no. 26, Dec. 30, 1927, p. 602. Discusses its properties and heat treatment; it is produced and used in all known forged forms; it is most conspicuous nonferrous material which has to be completely heat treated, that is, hardened by quenching and tempered; it is subject to corrosion to certain extent, but is less corrosive than steel. Lecture given before Co-ordinated Societies in Birmingham, England.

USES. New Uses of Duralumin (Neue Verwendungsgebiete des Leichtmetalles Duralumin), R. Beck. Zeit. für Metallkunde, vol. 19, no. 12, Dec. 1927, pp. 484-487, 6 figs. Deals with riveting of duralumin parts and gives examples of application; also examples of duralumin structural parts, such as motorcycle frames, ship-framework ribs, etc.; Brinell hardness of duralumin rivets.

## ELECTRIC FURNACES

ADVANTAGES. Electric Heating, C. L. Ipsen. Brass World, vol. 24, no. 1, Jan. 1928, pp. 5-8, 4 figs. Exposition of advantages of electricity over fuel; consideration of applications to relative cost of electricity and fuel; relative cost of heating process with fuel and electricity; copper and brass annealing; vitreous enameling; copper brazing; white-metal melting.

ANNEALING. Electric-Elevator Furnace Anneals Steel Castings, L. M. Bassini. Am. Mach., vol. 68, no. 4, Jan. 26, 1928, pp.

161-163, 4 figs. Car-type furnace of Burnside Steel Foundry Co.; heating chamber above floor so that full trackage space for movements of loads is available under furnace when it is in operation; work piled on annealing racks placed on car; car wheeled under furnace, and lifted into heating chamber; elevator operated by three-cylinder pump driven by electric motor; approximate output one ton per hour; temperature of 1650 deg. Fahr. obtained by four Nichrome ribbons; temperature controls are maintained by automatically operated switchboard.

ARC, ENERGY LOSSES. Energy Losses in Arc Steel Furnaces (Die Energieverluste an Lichtbogen-Elektrostahlöfen), St. Kriz. Stahl u. Eisen, vol. 48, no. 3, Jan. 19, 1928, pp. 71-72, 1 fig. Deals with transformer losses, cooling-water losses, heat-conduction and radiation losses; heat losses from apertures and openings, flue-gas losses, etc.

FOUNDRY. Fiat Electric Furnaces in Steel Foundries (Der Fiat-Ofen in der Stahlformgiesserei), E. Widdel. V. D. I. Zeit., vol. 71, no. 51, Dec. 17, 1927, pp. 1785-1789, 11 figs. Description of Fiat furnaces manufactured by Demag and A. E. G., principle of operation of electric installation; system of wiring; transportation of scrap, performance data and economy.

HEAT INSULATION. Heat Insulation of Electric Arc Steel Furnaces (Die Wärmeschutz von Elektrostahlöfen), H. Illies. Stahl u. Eisen, vol. 47, no. 52, Dec. 29, 1927, pp. 2228-2230, 3 figs. Presents curves showing heat conductivity and mean specific heat of refractory materials; temperature curves for non-insulated silica and insulated carborundum walls; concludes that in thin walls of highly refractory materials refractory insulating layer minimizes heat losses considerably.

HEAT TREATING. Selecting Electric Heat Treating Equipment. Machy. (Lond.), vol. 31, nos. 790 and 791, Dec. 1 and 8, 1927, pp. 257-259, and 313-315, 11 figs. Dec. 1: Explains various points to be considered in planning installations; electric furnaces of resistance type employed in heat treating work at temperatures up to 1850 deg. Fahr.; shell and supporting frame; door construction; various kinds of insulation; purpose of refractory lining; hearth construction; supporting heating elements. Dec. 8: Points to consider in planning installations; furnace voltage and control.

HIGH-FREQUENCY. The Metallurgy of High Frequency Induction Furnaces (Zur Metallurgie des Hochfrequenz-Induktionsofens), F. Wever and G. Hindrichs. Stahl u. Eisen, vol. 48, no. 1, Jan. 5, 1928, pp. 11-13, 2 figs. Results of tests with acid high frequency furnaces, and with basic 100-kw. furnace; tabular data on properties of steel obtained.

HIGH-FREQUENCY. Crucible Steel Production in a High-Frequency Electric Steel Furnace. Ry. Engr., vol. 49, no. 576, Jan. 1928, pp. 10-15, 6 figs. Ajax-Northrup high-frequency electric steel furnace effects revolution in production of tool steel by increasing capacity of crucible from 60 to 450 lbs., and reducing time of melting from 4 hours to 1 hour, while also affording better control; installed at Sheffield works of Edgar Allen & Co. See also Power Engr., vol. 23, no. 262, Jan. 1928, pp. 21-23, 3 figs.

INDUCTION. Electric Smelting Advancement, G. H. Clamer. Metal Industry (N. Y.), vol. 26, no. 1, Jan. 1928, pp. 11-12, 2 figs. Deals mainly with advances in art of metal melting due to introduction of vertical or submerged-ring type of induction furnace, and refers to more recent development of coreless induction type of furnace. (To be continued.)

MELTING. A Brief Review of Electric Iron and Steel Furnace Practice during 1927, W. E. Lewis. Iron and Steel Engr., vol. 5, no. 1, Jan. 1928, pp. 7-8. During past year about 30 new commercial-size iron and steel melting furnaces were added to United States supply; largest of these were two 25-ton furnaces; perhaps most noticeable tendency has been higher powering of number of equipments, especially those for steel castings and small billet-size ingots; hand charging is but little used except with smaller furnaces; most of new commercial-size melting furnaces operated with acid linings.

MELTING. Electric Furnace Practice, V. Stobie. Foundry Trade Jl., vol. 38, no. 595, Jan. 12, 1928, pp. 23-24. Author deals only with some special points; are temperature and quality; melting process, refining conditions; viscosity of electric steel. Includes brief discussion.

## ELECTRIC WELDING

METHODS. Electrical Welding and Hardening Processes. AEG Progress, vol. 3, no. 12, Dec. 1927, pp. 379-384, 20 figs. Electric salt-bath furnaces for hardening cutting tools; electric hardening furnaces for hardening carbon steel; electric annealing and tempering furnaces; two electric welding methods, arc welding and resistance welding; electric fusion butt welding employed in manufacture of highly stressed machine parts; sheets of metal welded together by spot welding; elasticity depreciated by electric arc welding; atomic arc-welding process.

## ELECTRIC WELDING, ARC

BUILDING CONSTRUCTION. Welding Structural Steel Buildings, A. M. Candy. Can. Engr., vol. 54, no. 3, Jan. 17, 1928, pp. 143-146, 3 figs. Design of steel structures for arc-welded connections discussed in paper presented at Civ. Eng. conference of Engrs.' Soc. of West. Pa. and reprinted from Proceedings of that society; tests made on beams with welded stiffeners and cover plates, also columns and their connections to beams.

ELECTRONIC TORNADO. Welding with "Electronic Tornado." Welding Engr., vol. 13, no. 1, Jan. 1928, pp. 39-40, 8 figs. New process adapted to automatic carbon arc welding has produced weld deposits of unusual characteristics; said to be low in operating cost; discovered in Research Laboratories of Lincoln Electric Co., Cleveland, Ohio.

METHODS AND EQUIPMENT. Some Considerations on Arc Welding and Choice of Equipment (Quelques considerations sur la soudure a l'arc electrique et sur le choix d'un equipement), F. Lorne. Electricite et Mecanique, no. 21, Nov.-Dec. 1927, pp. 23-

30, 9 figs. Suggestions on choice of equipment and information on method of utilizing current and electrodes for particular cases at hand; application to different metals and different kinds of welding.

NONFERROUS METALS. Nonferrous Metal Arc Welding, A. Churchward. Welding Engr., vol. 12, no. 12, Dec. 1927, pp. 41-42. Process of welding copper, brass, monel, bronze, nickel, aluminum and machinable cast iron welds; what to do and not to do in welding nonferrous metals; electrodes of various kinds for such welding.

PRESSURE VESSELS. The Application of Welding to the Construction of Large Pressure Vessels, T. McL. Jasper. Boiler Maker, vol. 28, no. 1, Jan. 1928, pp. 8-9. Fundamentals of good welding; explanation of results obtained from long series of tests on arc-welded specimens of carbon steels having a yield point of from 30,000 to 35,000 lb. per sq. in. and an ultimate strength of from 55,000 to 60,000 lb. per sq. in.

ROOF TRUSSES. Design for Welded Roof Trusses, W. Dalton. Welding Engr., vol. 12, no. 12, Dec. 1927, pp. 27-28, 5 figs. One piece construction using arc welded joints produces lighter member without loss of strength or serviceability; tests of welded joints in roof truss, made by Rensellaer Polytechnic laboratory; welds were fillet welds and tests were compressive and tensile.

## ELECTRIC WELDING, RESISTANCE

SPOT. Spot Welding Solves Factory Problems. Welding Engr., vol. 13, no. 1, Jan. 1928, pp. 29-30, 4 figs. Method employed making spot welds on electric refrigerators and ranges made by Edison Electric Appliance Co.; greater part of spot welding is used in attaching reinforcing strips to inside of box and to lining and door front.

THOMSON PROCESS. Electric Welding by Thomson Resistance Process (La soudure électrique par résistance procédé Thomson), A. Bidault des Chaumes. Génie Civil, vol. 92, no. 1, Jan. 7, 1928, pp. 9-12, 7 figs. Discusses process of welding by resistance when parts to be welded are held together and contacts are heated by low tension current until they fuse together; machines for welding are described and their advantages discussed with difficulties of installation; applications of this process are noted.

## ELECTRICAL INDUSTRY

METALLURGICAL PROBLEMS. Metallurgical Problems of the Electrical Industry, C. C. Paterson. Machy. Market, no. 149, Jan. 13, 1928, pp. 23-24. Practical review of recent research; consideration of overall cost of utilization; conductors heaviest items of capital expenditure on transmission; possibility of copper with same conductivity and higher tensile strength; possibilities of lighter metals, beryllium, lithium, boron, aluminum, when alloyed, not yet fully investigated; magnetic properties; composition; heat treatment and mechanical working. (To be continued.) Abstract of paper read before Inst. of Metals.

## FERROALLOYS

ELECTROLYTIC PRODUCTION. Electrolytic Manufacture of Ferroalloys (La fabrication électro-metallurgique des ferro-alliages), R. Galmard. Pratique des Industries Mécaniques, vol. 10, no. 10, Jan. 1928, pp. 397-401, 2 figs. Treats of ferrosilicon, ferromanganese, ferrochromium, ferrotungsten, ferromolybdenum, etc., their relation with iron and each other, their uses and how they are made, also touches briefly on electric furnaces. (To be continued.)

## FERRONICKEL

CHROMIUM ADDITION. Influence of an Addition of Chromium on the Internal Friction of Reversible Ferronickel (Influence d'une addition de chrome sur le frottement interne des ferronickels réversibles), P. Chevenard, Academie des Sciences—Comptes Rendus, vol. 185, no. 21, Nov. 21, 1927, pp. 1130-1132, 1 fig. Addition of chromium to reversible ferronickels of invar group extends range of temperature in which internal friction is relatively feeble; this effect, and its relation to anomaly previously recorded are shown in 3-dimensional diagram.

## FOUNDRIES

AUTOMOBILE PLANTS. 700 Tons Daily Melt of Auto Shop, P. Dwyer. Foundry, vol. 56, no. 1, Jan. 1, 1928, pp. 7-12 and 41, 13 figs. Third of series of articles describing methods and equipment employed in gray iron foundry placed in operation by Buick Motor Co., Flint, Mich.; deals with melting and coremaking departments.

BIBLIOGRAPHY. Treatise on Foundry Practice. Foundry Trade Jl., vol. 37, no. 592, Dec. 22, 1927, p. 213. Presents list of books dealing with foundry practice.

ELECTRIC POWER IN. Electric Power in the Foundry. Foundry Trade Jl., vol. 37, no. 592, Dec. 22, 1927, p. 214. Deals with miscellaneous application of electric power in foundry, such as driving of compressors, molding machines, fans, sand mills, hammers, etc.; preceded by details of a new all-electric charging equipment in an American foundry.

PARIS SHOW. The International Foundry Exposition of Paris, 1927 (Die Internationale Giessereifachausstellung in Paris), U. Lohse. V. D. I. Zeit., vol. 72, no. 1, Jan. 7, 1928, pp. 5-10, 9 figs. General descriptions of following divisions: raw materials, foundry materials, melting apparatus, molding machines, and processes; special notes on individual exhibits: the Bonvillain and Ronceray production system, Rosieres molding machine, Badische Maschinenfabrik's sandblasting molding machine. See also Giesserei, vol. 15, nos. 1, 2 and 3, Jan. 6, 13 and 20, pp. 6-10, 25-28 and 51-55, 31 figs.

PROGRESS, 1927. Foundrymen Gain in Metallurgy and Handling of Material. Iron Trade Rev., vol. 82, no. 1, Jan. 5, 1928, p. 38, 1 fig. Opinions of authorities on progress in foundry industry during 1927; labor-saving equipment, for conveying and handling; development of "high-test" castings; conservation of raw materials and improvement of product; greater production per molder; elimination of molding skill by mechanical devices; new era for foundries; attention to molding sands and core sands.

STEEL, INDUSTRIAL PROBLEMS. Over-Expansion in Steel Foundries, W. J. Corbett. Iron Age, vol. 120, no. 1, Jan. 5, 1928, pp. 35-36, 3 figs. Consumption of castings increased 37 per cent since 1913, but active capacity dropped from 75 to 55 per cent during same period; total sales of steel castings increasing steadily; acid and basic steel on a par; electric steel replacing converter steel; further expansion should be delayed until greater percentage of present capacity of steel foundries can be utilized to meet consumers' needs.

UNITED STATES. American Foundries Through European Eyes, M. Grindal. Iron Age, vol. 120, no. 1, Jan. 5, 1928, pp. 31-34, 2 figs. Democratic social system mainspring of American achievement; sees new market for malleable castings; suggests electric forehearth; stresses need for single cost language; freedom from caste is America's greatest asset; American molder aided by pneumatic equipment; forecasts improvement in molding machines; superior in materials-handling methods; molding sand, key to closer limits in castings.

UNITED STATES. Foundry Practice in the United States of America, E. Longdeen. Foundry Trade Jl., vol. 37, no. 593, pp. 225-231, 14 figs. Based on author's visit to American foundries in 1926; deals with industrial combinations, vocational training, methods of production, mass production, quality of metals used, etc.

## FURNACES, FORGING

LOCOMOTIVE SHOP. Better Forgings Produced through Furnace Control, E. J. Edwards. Iron Age, vol. 121, no. 2, Jan. 12, 1928, pp. 127-129, 5 figs. Billets charged in cool furnaces and heating cycle controlled by pyrometers; handling equipment; features of American Locomotive Co. shop; each morning two cool furnaces ready for charging, two hot furnaces containing steel ready for press and hammer and remaining two cooling off; two additional Stevens regenerative furnaces to heat wrought iron installed; equipped with Leeds & Northrup indicating and recording pyrometers; electric charging machine and manipulator; press and hammer equipment; extensive heat treating department; considerable testing required.

## FURNACES, HEAT TREATING

GAS-FIRED. Gas Hardening Furnaces in Brooklyn Plant. Iron Age, vol. 121, no. 3, Jan. 19, 1928, p. 197, 3 figs. In plant of Cameron Machine Co., Brooklyn, N. Y., gas-fired furnace is employed for hardening high-speed steel tools for machine shop; lead pots, similarly fired, are used for heat treating cutters and other high-speed steel.

## FURNACES, MELTING

ALUMINUM. Melting Pot and Crucible Furnaces in the Aluminum Industry, E. R. Thews. Metal Industry (Lond.), vol. 32, no. 1, Jan. 6, 1928, pp. 3-4. It is absolutely necessary that crucible furnaces employed for melting and remelting of aluminum and, particularly, for smelting of residues, should be heated with gas and oil; old stationary types of crucible furnaces have been replaced by tilting furnaces; graphite crucibles are almost exclusively used; grades of graphite available; treatment and storage of crucibles. (To be concluded.)

OIL-FIRED. An Oil-Fired Reverberatory Furnace for Melting Light Alloys. Foundry Trade Jl., vol. 38, no. 595, Jan. 12, 1928, pp. 31, 1 fig. Gives results of investigation of costs of melting aluminum alloy when using oil fuel; in a Midlands (England) installation, in order to make best use of oil firing, it was decided to employ low air-pressure system and at same time introduce simple form of recuperator; furnace tested was 6-cwt. tilter; aluminum was melted with oil consumption averaging between 6.4 and 6.6 lb. of oil per 100 lb. of metal, which compares with much higher figure of 9 to 10 lb. of oil per 100 lb. of metal with crucibles; time for melting down charge of 6 cwt. is well under half-an-hour.

## HARDNESS

BRINELL TEST. Methods of Hardness Testing. Am. Mach., vol. 68, no. 4, Jan. 26, 1928, p. 187, 3 figs. Brinell machines, their use and formulas briefly described; indentation effect of hard ball pressed into surface of metal to be tested; Brinell hardness number obtained by calculation from diameter of impression; machines hand-operated and motor driven; factors according to which deformation will vary; influences on depth of indentation; standard time should always be used; only testing of materials that will be deformed permanently under pressure, and of sufficient thickness and hardness to prevent bulging.

## HEAT TREATMENT

AUTOMOBILE PLANTS. Heat Treatment Plant. Machy. (Lond.), vol. 31, no. 796, Jan. 12, 1928, pp. 485-486, 2 figs. Layout and operation of heat treatment plant at Associated Daimler Co.'s works, Southall, Middlesex; carburizing and heat treatment of all parts requiring heat treatment; 15 August patent standard muffle furnaces fired by oil fuel, and 5 quenching tanks, 8 ft. diam., 3 of which are for oil and 2 for water quenching; 6 furnaces in use as carburizing furnaces; each of quenching tanks connected to Heenan patent cooling machines.

## IRON

CORROSION. The Action of Water, Air, Oxygen and Carbon Dioxide on the Corrosion of Iron, K. Inamura. Tohoku Imperial University—Sci. Reports, vol. 16, no. 8, Dec. 1927, pp. 979-986, 1 fig. Investigation to determine essential factor of corrosion; using Armco iron, action of distilled water, city water and sodium chloride solution upon iron was studied; also action or air, oxygen and $CO_2$ was studied and it was shown that action of $CO_2$ is weaker than that of oxygen, while $CO_2$ accelerates rate of corrosion by oxygen. (In English.)

CORROSION. An investigation of the Corrosion of Metals with a Thermobalance, K. Inamura. Tohoku Imperial University—Sci. Reports, vol. 16, no. 8, Dec. 1927, pp. 987-997, 8 figs. Aim of present work was to measure continuously change of weight in iron with progress of corrosion; results show only changes in weight of specimens in very early stage of corrosion; in general, iron

corrosion first occurs locally and gradually spreads over whole surface. (In English.)

REFINED. Modern Refined Irons, J. E. Hurst. Foundry Trade Jl., vol. 38, no. 595, Jan. 12, 1928, p. 30. Points out that term "refined iron" has been familiar in iron trade for many years, but there has always been some uncertainty as to its exact meaning and character of product which it was intended to define; in Patents Office classification term is loosely used to cover product of refinery furnaces, whether pig iron, malleable iron or steel; modern refined pig irons.

## IRON ALLOYS

IRON-CARBON. The Metastable Nature of Iron Carbide, A. Hayes. Iowa State College of Agriculture & Mechanic Arts—Official Publication, vol. 26, no. 1, June 1, 1927, 51 pp., 21 figs. Free energy and heat of formation of iron carbide for temperature interval 650-700 deg. Cent.; calorimetric determination of heat formation of iron carbide at room temperatures; graphitizing behavior of pure iron-carbon alloys in critical range.

PROTECTIVE COATINGS. Treatment of Articles of Ferrous Alloys in Solutions of Complex Phosphates as a Protection Against Corrosion (Sur le traitement des pièces en alliages ferreux dans des solutions de phosphates complexes, etc.), J. Cournot. Académie des Sciences—Comptes Rendus, vol. 185, no. 20, Nov. 14, 1927, pp. 1041-1043. Clean iron, or ferrous alloys, immersed in bath of boiling acid solution (3-4 per cent) of iron and manganese phosphates, liberate small quantity of hydrogen and then become coated with adherent gray-black deposit of secondary phosphate of iron, about 0.005 mm. thick; on account of its close adherence to metal it is less vulnerable to localized corrosion. See brief translated abstract in Chem. & Industry, vol. 47, no. 1, Jan. 6, 1928, p. 18.

## IRON AND STEEL

ANALYSIS. Quick Analysis in Iron Metallurgy (L'analyse rapide en siderurgie), J. Navarro. Chimie & Industrie, vol. 18, no. 6, Dec. 1927, pp. 993-996, 3 figs. Describes apparatus for quick determination of carbon, of manganese, of silica, of sulphur, of phosphorus and oxygen; methods described have been in use for 2 years in metallurgical laboratory in France.

CARBON DETERMINATION. A Quick Method for Determining the Carbon Content of Iron and Steel, S. Stroyev. Russkoye Metallugicheskoye Obshchestvo Jl., no. 4, part 1, 1927, pp. 362-369, 3 figs. Shortcomings of the von-Hohn and de Nolly methods; principles and operation of method developed by author at laboratories of Russian Government aviation plant No. 2; tests of method showing very close agreement with Corleis and Mars methods.

BIBLIOGRAPHY. Review of Iron and Steel Literature for 1927, E. H. McClelland. Blast Furnace and Steel Plant, vol. 16, no. 1, Jan. 1928, pp. 20-23 and 33. Classified list of more important books, serials and trade publications during year; with few of earlier date not previously announced.

CORROSION. Corrosion in Ice Plants, H. L. Lincoln. Ice & Refrigeration, vol. 74, no. 1, Jan. 1928, pp. 31-33. Author gives resume of causes of ice-can corrosion; research has demonstrated that corrosion could be prevented; remedies suggested; this work has been very thorough and great many sets of accurate tests made of rate of corrosion on iron, steel and galvanizing to determine conditions affecting corrosion and materials that might be used as retarders; as matter of interest over 20 materials have been tested in laboratory and those showing most promise given plant trials.

EUROPEAN INDUSTRY. European Mills Face a Struggle for Foreign Markets in 1928. Iron Age, vol. 121, no. 2, Jan. 12, 1928, pp. 140-142. Decline of home demand may make Germany larger exporter while Britain seeks to regain lost customers; France must retain heavy exports. Great Britain—efforts made to reduce imports; competition of foreign iron serious; mills watch international cartel; Germany—establishment of 8-hr. day postponed; year of heavy production; domestic mergers and new cartels numerous; France—year of declining prices; iron ore output shows increase; iron and steel production smaller; imports smaller and exports increase.

EXPORTS AND IMPORTS. Exports and Imports Both Increase. Iron Age, vol. 121, no. 2, Jan. 12, 1928, pp. 175-176. November higher than October; 11-month total of exports 2 per cent above 1926; imports 33 per cent lower; tables showing exports of iron and steel from United States, imports of iron and steel into United States and destination of iron and steel exports from United States.

INDUSTRY. Iron and Steel, B. E. V. Luty. Am. Metal Market, vol. 25, no. 14, Jan. 21, 1928, pp. 3-4. Year off but little in tonnage with recovery probable in 1928; service of steel increased; better marketing methods in making; production statistics for pit iron, semi-finished steel, rails, plates, shapes and bars, wire products, tubular goods, tin plate, sheets and scrap.

INDUSTRY. Less New Capacity in 1927. Iron Age, vol. 120, no. 1, Jan. 5, 1928, pp. 78-83. No blast furnaces added; open-hearth increase 630,000 tons in 1927; expansion for 1928 very light; few electric furnaces sold; expansion in steel, iron and rolling mill capacity; two open-hearth units planned for 1928; two new blast furnaces in 1928; several furnaces rebuilt and enlarged; new construction and improvement of steel corporations completed during 1927 and under way; additions to rolling mills; extensions to foundries.

OXYGEN IN. Oxygen in Iron and Steel (Sauerstoff in Eisen und Stahl), P. Oberhoffer, H. J. Schiffler and W. Hessenbruch. Archiv für das Eisenhüttenwesen, vol. 1, no. 1, July 1927, pp. 57-68, 6 figs. Report on theoretical and laboratory study, done at Aachen Institute of Technology, on effect of oxygen content of microstructure of steels; modifying character of steel alloys by adding oxygen; fracturing of steel of high oxygen content.

PRICES. Iron and Steel Prices for Sixteen Years. Iron Age, vol. 120, no. 1, Jan.

5, 1928, pp. 111-125. Monthly averages computed from weekly market quotations of Iron Age in period of 1912 to 1927; two-colored charts indicate course of prices for pig iron, billets, scrap and leading forms of finished iron and steel and nonferrous metals; tables of monthly average prices of 80 products.

## IRON CASTINGS

ALLOY. Production and Uses of Nickel-Chromium-Iron and Cobalt-Chromium-Iron Castings, J. F. Kayser. Iron & Steel World, vol. 1, no. 10, Nov. 1927, pp. 717-718. Description of Ni-Cr-Fe and Co-Cr-Fe alloys suitable for castings; properties and uses of such alloy castings; "stainless" alloys. Abstract of paper read before Belgian Foundrymen's Assn.

DIESEL ENGINES. The Production of Diesel Engine Castings in Pearlitic Cast Iron. Foundry Trade Jl., vol. 37, no. 592, Dec. 22, 1927, pp. 215-216. Discussion of lecture by A. J. Richman before Inst. Brit. Foundrymen; points out close relationship between resistance to wear and Brinell hardness number.

DIRTY. What Causes Dirty Castings? W. F. Prince. Foundry, vol. 56, no. 1, Jan. 1, 1928, pp. 19-20. Extended experiments showed that agitation of molten iron either by air or steam throws out sulphur and manganese in form of excessive slag, in author's opinion machine-cast pig is not as good as sand-cast pig; machine-cast pig boils more in casting, creates more oxide and deposits more oxides in cupola which never go back into metallic form.

ENGINEERING STANDARDS. Is the Foundry Approaching the Engineer's Standard? M. E. Nicholls. Foundry Trade Jl., vol. 38, no. 594, Jan. 5, 1928, p. 10. Foundry products have improved considerably during recent years, and it can truthfully be said that (slowly perhaps) foundry is approaching engineer's standard; what remains to be done is to classify standards so that there will be no ambiguity, and then classify foundries, so that each knows its prescribed standards and can develop its resources accordingly.

OIL-SAND MIXTURE. Some Further Notes on Oil-Sand and Motor Cylinders, W. West. Foundry Trade Jl., vol. 37, no. 592, Dec. 22, 1927, pp. 211-213, 5 figs. Results given represent beginning of extensive series of practical experiments to explore nature and use of all media which might be of service to foundrymen in oil-sand mixture; rosin as an agglomerant; effect of mixing and milling upon grain size of sand mixture.

## IRON METALLURGY

DEVELOPMENTS. Metallurgical Developments of 1927, S. Goodale. Blast Furnace and Steel Plant, vol. 16, no. 1, Jan. 1928, pp. 46-48. Important new advances made during year in blast furnaces and foundry practice and in steel-plant equipment and operations and rolling-mill design.

## IRON, PIG

AMERICAN INDUSTRY. What Ails the Merchant Pig Iron Industry of America? J. F. Froggett. Iron Trade Review, vol. 82, no. 1, Jan. 5, 1928, pp. 17-19 and 23-24, 1 fig. Decline from 42 to 23 per cent of merchant iron to total in quarter century shows decadence of industry; hope for future lies in economical integration, including sources of materials consumed; history of merchandising pig iron; distinction grows dimmer between merchant and nonmerchant stacks; buyers turn competitors; annual per capita production of pig iron; proportion of merchant pig iron to all pig iron decreased steadily until in 1927 it reached low percentage of 23.1 per cent; furnace capacity soars; day of big productive stack definitely here, for merchant as well as for steel works; war brought maximum of active blast furnaces; present return inadequate.

PROGRESS. More Pig Iron, Better Pig Iron, Protective Freight Rates, E. J. Lowry. Iron Age, vol. 120, no. 1, Jan. 5, 1928, pp. 60-61, 2 figs. Common problems of merchant furnaces and foundry industry; steep inwalls successful in South; does large tonnage mean inferior iron discussed; special irons for special purposes; slightly more charcoal iron sold; freight rates have profound influence on furnace activities.

## LEAD

EMBRITTLEMENT. The Intercrystalline Embrittlement of Lead (Die Interkristalline Brüchigkeit des Bleies), O. Haebnel. Zeit. für Metallkunde, vol. 19, no. 12, Dec. 1927, pp. 492-496, 3 figs. Critical discussion of causes of embrittlement of lead-covered cables and water pipes; additions of tin and antimony increase resistivity of lead at ordinary temperature; influence of other metals has not yet been investigated.

PROPERTIES AND USES. The Use of Lead in Engineering Practice, O. W. Ellis. Brass World, vol. 24, no. 1, Jan. 1928, pp. 11-13, 1 fig. Discusses alloys, properties and practical applications of lead; tabular data on relative hardness of metals, and tensile strengths and density of commoner metals. Paper read before Am. Inst. Chem. Engrs. (To be concluded.)

## MALLEABLE CASTINGS

MOLDING. Some Methods of Production in a Modern Malleable Iron Foundry, A. J. Beck. Foundry Trade Jl., vol. 38, no. 594, Jan. 5, 1928, pp. 7-9, 20 figs. Details methods of molding that have enabled Leys Co. to produce over 10,000 tons of malleable castings during last 12 months; types of machines used; sandslingers.

## MANGANESE STEEL

PROPERTIES. Manganese Steel, Its Manufacture and Properties (Acero al manganeso, su fabrication y propiedes), J. Vazquez. Anales de la Asociacion de Ingenieros del Instituto Catolico de artes e Industrias, vol. 6, no. 6, 1927, pp. 485-494, 4 figs. Author discusses its properties, uses, metallography and chemistry; also heat treatment, physical and mechanical characteristics, resistance to wear and fatigue, and finally manufacture.

## METALLOGRAPHY

STEEL. Atlas Metallographicus, H. Hanemann and A. Schrader. Foundry, vol. 56, no. 1, Jan. 1, 1928, p. 28. Review of atlas published by Geb. Borntraeger, Berlin, Ger-

many; part 1 includes description of various formations such as ferrite, cementite and pearlite in carbon steel slowly cooled and annealed; also includes iron-carbon diagram; 8 tables and 64 micrographs; part 2 contains 8 tables with their accompanying 57 micrographs showing structure of unalloyed, forged steels of various analysis.

## METAL INDUSTRY

PROGRESS. Progress of Metals in 1927; Outlook for 1928. Metal Industry, vol. 26, no. 1, Jan. 1928, pp. 19-24. Survey containing following contributions: Copper Industry, W. A. Willis; Lead and Tin Progress, G. O. Hiers; Zinc, S. S. Tuthill; Aluminum in 1927; Recent History of Nickel, W. B. Lawson; Precious Metals, C. M. Hoke.

UNITED STATES. Metal Industries of the United States. Metal Industry (N. Y.), vol. 26, no. 1, Jan. 1928, pp. 16-17, 1 fig. Present metal industries are listed in each state and number of plants are shown with these listings.

## METALS

AIRCRAFT CONSTRUCTION. Aircraft of Increasing Importance to Metal Industries, H. C. Knerr. Iron Age, vol. 120, no. 1, Jan. 5, 1928, pp. 14-16, 4 figs. To aviation's demands will be added those due to changes air travel will cause in modes of land travel; map of United States subdivided into states; importance of air transportation assures large and steadily growing industry; materials developed for aircraft prove of great utility to other industries; new market for welding equipment, new technique and new standards of excellence for welded structures; corrosion prevention; rigorous technical control of materials and processes.

COHESION. Cohesion. Metallurgist (Supp. to Engineer), Dec. 30, 1927, pp. 177-178. Refers to recent discussion on cohesion organized by Faraday Society which served to show how much still remains unknown in regard to atom and its means of attachment to its neighbors; when it is known why and how cohesion is developed to such widely varying degrees in different materials, metallurgists will have key to selection of those best suited for given purpose, but to production of new combinations of matter, but understanding of fundamental phenomena of cohesion is still very remote.

CORROSION. Corrosion by Oil Fuels (Korrosion durch Kraftstoffe). Korrosion u. Metallschutz, vol. 3, no. 12, Dec. 1927, pp. 270-274, 6 figs. Results of investigations of effect of gasoline, benzol, and benzol-alcohol on different metals; effect of different liquid fuels on copper wire, and their effect on a combination of two or more metals, such as often occurs in automobile engines, etc.

CRYSTAL STRENGTH. Strength of Metallic Crystals (Festigkeitseigenschaften von Metallkristallen), von Goeler and G. Sachs. Zeit. fuer Technische Physik, vol. 8, no. 12, 1927, pp. 586-594, 15 figs. Report from Kaiser Wilhelm Inst. for metal research; methods of growing large single crystals of metals and determination of orientation of axes of crystals; tensile tests; transformation equations of tensile tests; strength and elongation.

FUSION HEAT. On the Latent Heat of Fusion and Heat of Transformation of Some Metals, S. Umino. Tohoku Imperial Univ.—Science Reports, vol. 16, no. 7, Oct. 1927, pp. 775-798, 9 figs. Heat contents of manganese, thallium, carbon steels containing 0.57 per cent, 0.94 per cent, 1.16 per cent and of pig iron containing 4.31 per cent and 1.11 per cent Si measured at high temperatures by differential calorimetric method; both mean and true specific heat have been deduced, and mean value of heat of Ac transformation in cementite found to be 9.72 calories. (In English.)

HIGH TEMPERATURES, EFFECT OF. The Behaviour of Metals at High Temperatures, P. Henry. Metallurgist (Supp. to Engineer), Dec. 30, 1927, pp. 180-181. Review of paper published in Revue de Metallurgie Aug. 1927, giving an account of recent work carried out on rate of deformation during prolonged loading of materials in plastic state; materials used were steel and electrolytic copper in form of cylindrical test pieces; results show that, whereas mechanical strain at proportional limit decreases with temperature, total strain increases; decrease in modulus of elasticity with temperature shows that stress required to produce given spacing decreases with temperature.

HYSTERESIS. Hysteresis in Relation to Cohesion and Fatigue, B. P. Haigh. Metal Industry (Lond.), vol. 31, no. 25, Dec. 23, 1927, pp. 584-585. According to views advanced, "elastic hysteresis should no longer be regarded as an incidental imperfection of more ideal state of elasticity represented by Hooke's law, but rather as an inherent characteristic of state of elasticity that can be acquired by metals; and that state of elasticity should be attributed to influence of grain boundaries and surfaces of slip within grains, rather than to crystalline metal. Paper read before Faraday Soc.

NITROGEN IN. Gases in Metals: III The Determination of Nitrogen in Metals by Fusion in Vacuum, L. Jordan and J. R. Eckman. U. S. Bur. Standards—Scientific Papers, no. 563, Oct. 18, 1927, pp. 468-485, 2 figs. Complete vacuum-fusion procedure was applied to analysis of several synthetic nitrides (silicon, aluminum, titanium, zirconium, chromium, vanadium) and few irons and steels; results obtained were compared with nitrogen values given by usual acid-solution method for nitrogen in metals; fusion method has precision equal to that of solution method and gives higher values for nitrogen than solution method in analysis of nitrides of silicon, titanium, and vanadium and in certain iron and steel samples; fusion method should determine also any "uncombined" nitrogen present in metal.

PRICE FLUCTUATIONS, 1920-1927. Metal Price Fluctuations. Am. Metal Market, vol. 25, no. 14, Jan. 21, 1928, supp. plate. Fluctuations shown on this chart represent monthly averages for past eight years plotted on percentage basis with averages for ten years 1904 to 1913 which are taken to represent normal pre-war values.

TESTING. On the Process of the Failure of Metals under Tensile Stress, K. Yausa. Imperial Acad. of Japan—Proc., vol. 3, no. 9, Nov. 1927, pp. 603-606, 7 figs. Failure of metals under stress depends not only upon

properties of metals, but also on temperatures and loading speeds to which they are subjected. (In English.)

## MOLDS

INGOT. Ingot Mold Life and Chemical Analysis, E. H. Williams. Blast Furnace and Steel Plant, vol. 16, no. 1, Jan. 1928, pp. 29-30. Points out that in order that ingot molds may give greatest return chemical composition and temperature of iron must be within specific limits; mold failure; how growth may be retarded; special iron mixture.

INGOT, COPPER. Water-Cooled Copper Ingot Molds (Wassergekuehltekokillen), W. Rohn. Zeit. fur Metallkunde, vol. 19, no. 12, Dec. 1927, pp. 473-478, 13 figs. In chill molds resistance to heat transmission is greater in mold wall than on boundary surface between mold wall and cooling water; water-cooled copper molds with cooling ducts can be used for nickel of 1650 deg. casting temperature for casting in vacuum and remain wholly unchanged after being used 1000 times; notched-bar values of ingots cast in such molds are higher.

## NICKEL

ARMAMENT. Nickel in Armament (Le nickel dans l'armement), M. G. Charpy. Revue de Métallurgie, vol. 24, no. 12, Dec. 1927, pp. 715-721, 8 figs. History of use of nickel in projectiles, armor plate and cannon with description of some armor-plate tests; case hardening or surface hardening by Krupp nitration process is described and its effect on piercing by projectiles.

INDUSTRY. Outline of the Nickel Industry (Apercu sur l'industrie du nickel), R. C. Stanley. Revue Universelle des Mines, vol. 17, no. 1, Jan. 1, 1928, pp. 36-50, 2 figs. History, production and prices of nickel, 1840-1926; tables, classification of products of nickel, alloys, monel metal, nickel steels, castings, etc.

IRON AND STEEL CASTINGS, IN. Nickel in Casting of Iron and Steel (Le nickel dans les moulages de fonte et d'acier), J. Galibourg. Revue de Métallurgie, vol. 24, no. 12, Dec. 1927, pp. 730-739, 11 figs. Author presents brief outlines of whole question, emphasizing only points least known or of recent origin; nickel and nickel-chromium castings and influence of various chemicals on castings, metallographic study of heat heated castings containing nickel and of cast nickel steel.

## NICKEL ALLOYS

CORROSION. Nickel Alloys and their Corrosion (Les alliages de nickel et la corrosion), A. Portevin. Revue de Métallurgie, vol. 24, no. 12, Dec. 1927, pp. 697-703, 3 figs. General review of corrosion of metals and alloys and importance of study of their resistance to chemical action followed by discussion with tables, of effect of various acids on alloys of nickel.

NONFERROUS. Nonferrous Alloys of Nickel (Les alliages de Nickel non-siderurgiques), J. Cournot. Revue de Métallurgie, vol. 24, no. 12, Dec. 1927, pp. 740-763, 31 figs. Extensive review of principal properties of each kind of alloy, their characteristics, use and metallographic study with charts of various kinds; nickel-cobalt, nickel-manganese, nickel-copper, nickel-molybdenum, zinc, tin, lead, silver, gold, platinum; also bronzes and brasses are treated.

## NICKEL STEEL

AUTOMOTIVE APPLICATIONS. Nickel in Automobile and Aircraft Industries (Le nickel dans les industries de l'automobile et de l'aviation), L. Guillet. Revue de Métallurgie, vol. 24, no. 12, Dec. 1927, pp. 722-729. Review of all possible applications of nickel in nickel steels used in automotive industries, history, usual type of nickel steel, chromium-nickel steel, complex types of steel using nickel as an alloy.

## NONFERROUS METALS

CANADA. The Miscellaneous Nonferrous Metal Products Industry in Canada, 1926. Metal Industry (Lond.), vol. 31, no. 26, Dec. 30, 1927, p. 603. Production amounted, according to Dominions Bureau of Statistics, to $998,512 in value, as compared with $999,277 reported for previous year.

ENGLAND. Review of Nonferrous Metals Trade on N. E. Coast in 1927. Metal Industry (Lond.), vol. 32, no. 2, Jan. 13, 1928, pp. 43-45, 3 figs. Production of lead, copper and silver, as well as of antimony, are among industrial activities of North East Coast, which is otherwise almost wholly devoted to manufacture of iron and steel and to engineering and shipbuilding; chief lead-mining undertaking, some of which date back some centuries, is that of Weardale Lead Co., while Bede Metal & Chemical Co., at Hepburn, is largest copper-smelting works; detailed account of undertaking of these two enterprises.

ENGLAND. Birmingham and its Nonferrous Metal Industries, F. Johnson. Metal Industry (Lond.), vol. 32, no. 2, Jan. 13, 1928, pp. 33-36, 21 figs. Deals with metallurgical industries of Birmingham, England, their early history and subsequent developments; classification of copper and brass trades; early modes of wire making; newer methods and improved practice.

GERMANY. The German Nonferrous Metal Industry in 1927. Metal Industry (Lond.), vol. 32, no. 2, Jan. 13, 1928, pp. 66-69, 5 figs. Three features were characteristic of development; effort to increase home production of nonferrous metals, export bounty agreement between rolling mills and manufacturers of nonferrous metal products, and boom which followed depression during years 1925 and 1926; prospective demand for nonferrous metals; imports; gives chief German producers of nonferrous metals.

INDUSTRY. Copper, Tin, Zinc Markets Reviewed, Iron Age, vol. 120, no. 1, Jan. 5, 1928, pp. 72-73. Authorities in trade survey course of production; stocks and prices in 1927. Contains following contributions; Copper Market Has a Bright Future, by H. M. Brush; Tin Prices Not Likely to Decline Much, by J. P. Wilson; Zinc Values Touched Lowest Levels in Five Years.

METALLURGY. Progress in Nonferrous Metallurgy During 1927, J. Silberstein. Brass World, vol. 24, no. 1, Jan. 1928, pp. 14-15. Advances in alloying and heat treating metals; developments in aluminum, beryllium,

copper and its alloys, and magnesium; thin metal films; properties of very pure metals.

METALLURGY. The Metallurgy of Nonferrous Metals in 1927, C. O. Bannister. Metal Industry (Lond.), vol. 32, no. 3, Jan. 13, 1928, pp. 30-31. Wide range which research has covered during past year, in regard alike to metallurgical processes, to investigation of influence of impurities, corrosion, and its prevention, and commercial development of new alloys; note on growing importance of nickel, and progress made in plating processes.

PRICES. Metal Prices, 1927. Metal Industry (Lond.), vol. 32, no. 2, Jan. 13, 1928, p. 63, 1 fig. Presents chart showing weekly averages of official daily prices on London metal exchanges, for standard copper, standard tin, soft lead and spelter (g.o.b.), and gives actual figures of main price features of these metals during 1927, with comparative figures for 1925 and 1926.

PROGRESS. Marked Progress in Nonferrous Metallurgy Last Year, W. M. Corse. Iron Age, vol. 120, no. 1, Jan. 5, 1928, pp. 69-71. Copper—advantages broadcast; lead—no spectacular progress; zinc—new processes and alloys zinc-base magnesium-bearing alloy designed for die casting; nickel, new outlets developed; monel metal has new fields; solid nickel-silver plumbing fixtures; aluminum and magnesium-Alclad, new aluminum sheet, has strength and corrosion resistance; trend in lighter weight in transportation; magnesium expansion; chromium, and chromium plating expands.

RESEARCH. How Research Developed the Nonferrous Metal Industries, W. M. Corse. Metal Industry (N. Y.), vol. 26, no. 1, Jan. 1928, pp. 14-17. Brief review of research on nickel, copper, aluminum bronze, zinc, aluminum, lead, and chromium.

SOUTH WALES. The Nonferrous Metal Industries of South Wales, W. R. D. Jones. Metal Industry (Lond.), vol. 32, no. 2, Jan. 13, 1928, pp. 37-42, 7 figs. South Wales possesses many works engaged in production of copper, zinc, and nickel, and in refinement of two first-named metals; deals exhaustively with Welsh nonferrous industries.

STATISTICS. Nonferrous Metals: Statistics and Prices. Metal Industry (Lond.), vol. 32, no. 2, Jan. 13, 1928, pp. 28-29. Data on general situation in 1927, market conditions and their copper, tin, lead and zinc.

## OXYACETYLENE CUTTING

CAST IRON. Oxyacetylene Cutting of Cast Iron (Ueber das Brennschneiden von Gusseisen), I. C. Fritz. Gas und Wasserfach, vol. 70, no. 43, Oct. 22, 1927, pp. 1048-1049, 3 figs. Cast iron has hitherto presented difficulties to flame cutting, since it melts before it burns, and its oxide melts before metal itself; this difficulty is overcome by new type of oxyacetylene burner, in which oxygen is preheated by passing over nozzles, and which, by first burning carbon in cast iron, allows remaining iron to be easily cut.

FOUNDRIES. Notes on Oxyacetylene Cutting in Foundries, C. H. S. Tupholme. Foundry Trade Jl., vol. 37, no. 592, Dec. 22, 1927, p. 216. Points out that proper use of oxyacetylene cutting flame has enabled many foundry managers to reduce their rejections, and flame, when employed for cutting risers, has exerted an important influence on modern casting practice, cutting flame may play an equally important part in reclamation of defective castings, particularly where defect is minor in degree, such as blowhole, a shrinkage crack or part of a lug missing; another opportunity to use flame for reclamation is in case of aluminum castings.

## OXYACETYLENE WELDING

ALUMINUM SHEET. Welding Aluminum Sheet. Mech. Wld., vol. 82, no. 2137, Dec. 16, 1927, pp. 449-450, 3 figs. That oxyacetylene welding fulfills all requirements is illustrated by fact that practically every aluminum airplane tank manufactured in America is built with oxy-welded seams; of utmost importance in this work is selection of proper material for welding; good flux is also important.

BRASS CASTINGS. The Reclamation of Defective Brass Castings, P. W. Blair. Metal Industry (N. Y.), vol. 26, no. 1, Jan. 1928, p. 10. Use of oxyacetylene torch for repair work in foundry.

PRESSURE VESSELS. Procedure Control in Pressure-Vessel Welding, H. E. Rockefeller. Mech. Eng., vol. 50, no. 2, Feb. 1928, pp. 133-136, 5 figs.; also Boiler Maker, vol. 22, no. 12, Dec. 1927, pp. 346-348, 3 figs. Points out how factors comprising term "procedure control" were applied; indicates how, by analysis of these factors, valuable progress can be made; welded pressure vessels constructed in accordance with procedure-control methods are perfectly safe for operation, and are probably safer than any other present form of fabricated-plate pressure-vessel construction.

RAILS. 100,000 Welds Made in Rail Electrification. Oxyacetylene Tips, vol. 6, no. 6, Jan. 1928, pp. 101-104, 3 figs. Electrical contractor makes 50,000 rail-end copper wire bonds over 120 track miles of suburban system; bonds consisted of 127 strand number 4/0 copper wire about 1 ft. long; much of work was done at night, especially in downtown district when traffic during day was too heavy to permit of anything but intermittent work; total cost of project amounted to about $150,000.

## REFRACTORIES

IMPROVEMENTS. Refractories Research Points Way to Quality and Uniformity. Iron Trade Rev., vol. 82, no. 1, Jan. 5, 1928, p. 39, 1 fig. Opinions of authorities in field of refractories regarding 1927 improvements; improvement of common as well as "super" refractories; better quality, greater uniformity of size and extended use of delivery presses and tunnel kilns in manufacturing processes; production of better inwall brick for blast furnaces, improved silica brick from automatic molding machines; advantageous use of high alumina brick in open-hearth and more efficient use of basic and neutral refractories for special problems; progress in use of newer materials; rapid growth in use of minerals in sillimanite family for higher quality refractories.

## ROLLING MILLS

IMPROVEMENTS. New Ideas Overturn Traditions in Rolling Mill Industry. Iron Trade Rev., vol. 82, no. 1, Jan. 5, 1928, pp. 32-33, 2 figs. Opinions of authorities on 1927 developments in rolling steel; installation of mills for rolling wide strips; accurate mechanical production of sheets; many advantages of continuous process; economic status of new mills; installation of mill designed for wide flange beams; more general use of anti-friction bearings; electric drives; developments in mills for rolling practically every material.

ROLL-NECK BRASSES. Roll Neck Brasses for Sheet and Tin Mills. Blast Furnace and Steel Plant, vol. 16, no. 1, Jan. 1928, pp. 4-7 and 11. Engineer who has had many years of experience relates procedure in making a study of service given by brasses of varying composition; results are tabulated; studies show that breaking of rolls does not affect consumption of brass to any great number; nor does operating practice which results in high or low roll breakage seem to bear any definite relation to number of brasses used.

SHEET MILLS. Many Factors Participated in Development of Continuous Sheet. Iron Age, vol. 120, no. 1, Jan. 5, 1928, pp. 77 and 109, 2 figs. Administration of patents and economic relation of strip mills to new and old style sheet mills; new method of making sheets by law of economics applicable only to large tonnage plants; surface condition and grain structure improved; precision without precedent; higher grade of skilled mechanics required; studies in finishing departments.

## ROLLS

CHILLED. The Use and Abuse of Chilled Rolls, W. H. Melaney. Blast Furnace and Steel Plant, vol. 16, no. 1, Jan. 1928, pp. 12-15, 2 figs. Relates in concise form how rolls are manufactured and how they should be handled when in service; refers especially to sheet-mill rolls; chilled cast iron is most desirable because of its cheapness, its hard face and fact that heat it must stand in rolling sheets has very little effect in reducing hardness; physical characteristics.

## SCRAP METAL

CLASSIFICATION. Scrap Metals in America. Metal Industry (Lond.), vol. 32, no. 1, Jan. 6, 1928, pp. 11 and 15. Presents standard classification for old metals drawn up by committee and approved by meeting of Metal Division of Nat. Assn. of Waste Material Dealers. (Concluded from Dec. 16, 1927.)

## SCRAP STEEL

MACHINE-TOOL CASTINGS. Casting Semi-Steel Machine Tool Parts at Galt, E. G. Brock. Can. Machy. and Manufacturing News, vol. 38, no. 26, Dec. 29, 1927, pp. 182-184 and 187, 4 figs. History and manufacturing activities of Canada Machinery Corp.; semi-steel used for parts; semi-steel castings eliminate warping; foundry practice; many large castings made in green sand; means of dropping cupola bottom after daily heat; several steps in process of molding 10-ton bull-dozer frame; hard dry sand gate; reinforcing with rods; spacious core-room; conditions existing in plant reflected in product.

## SLAG

BLAST-FURNACE. Blast-Furnace Slag as Railway Ballast (Versuche mit Hochofenstueckschlacke als Gleisbettungsstoff), H. Burchartz and G. Saenger. Stahl u. Eisen, vol. 47, no. 40, Oct. 6, 1927, pp. 1663-1664. Composition of blast-furnace slag in Germany; it is slightly poorer on railroad track than basalt in its resistance to frost and crushing, but is better than granite; rusting of iron is somewhat accelerated during first year, but thereafter it has no effect. See English translation in Rock Products, vol. 31, no. 2, Jan. 21, 1928, p. 96.

## STEAM PIPES

HIGH-PRESSURE. High-pressure Steam: Its Demands on Piping, A. L. Walker. Mech. Wld., vol. 82, no. 2137, Dec. 16, 1927, p. 448. Steel castings have to great extent replaced those of cast iron; gradually difficulties of obtaining homogeneous metal have been reduced; forged flanges are superior to cast ones; design of joints; metal used for nuts is usually a straight carbon steel; in author's opinion demands made by high-pressure steam call for no radical changes of design; rather do they push design along path which is right, but which hitherto manufacturers have not been forced to follow.

## STEEL

FATIGUE. On the Fatigue of Steels for Springs, Axles and Rails, S. Ikeda. (Japan) Dept. of Railways—Bul., vol. 15, no. 11, Nov. 1927, pp. 1745-1774, 32 figs. (In Japanese.)

HEAT OF TRANSFORMATION. On the Heat of the $A_2$ and $A_3$ Transformations in Carbon Steels, S. Umino. Tohoku Imperial University—Sci. Reports, vol. 16, no. 8, Dec. 1927, pp. 1009-1030, 7 figs. Heat contents of carbon steels containing 0.040, 0.135, 0.270, 0.350 and 0.770 per cent. have been measured at high temperatures; from results, both mean and true specific heat have been deduced, and it was found that $A_2$ transformation in pure iron takes place in range of about 130 deg. Cent.; heat of this transformation was found to be 3.65 calories, while that of $A_3$ transformation was 5.35 calories. (In English.)

HIGH TEMPERATURES, EFFECT OF. The Mechanical Properties of Steel at High Temperatures, H. J. Tapsell and W. J. Clenshaw. Eng., vol. 124, no. 3233, Dec. 30, 1927, p. 837, 6 figs. Review of Eng. Research Special Report, No. 2, describing work on mechanical properties of materials at high temperatures being carried out at National Physical Laboratory; work was done on 0.51 per cent carbon steel in rolled bars of 1 in. diam., said to have been normalized before delivery, and 0.53 per cent carbon cast steel.

INGOTS, PRODUCTION 1927. Another Increase in Ingot Production. Iron Age, vol. 121, no. 2, Jan. 12, 1928, pp. 167c-167d, 1 fig. Chart showing production of steel ingot from 1920 to 1927; table of production of steel ingots; December pig iron data.

MANGANESE, EFFECT OF. The Effect of Manganese on the Properties of Low-Carbon Steels, J. A. Jones. Metallurgist (Supp. to Engr.), Oct. 28, Nov. 25 and Dec. 30, 1927, pp. 151-154, 166-169 and 186-187, 4 figs. Crucible steels; effect of normalizing temperatures; slow cooling and oil quenching. Nov. 25: Examination of commercial plates. Dec. 30: High elastic limit structural steels; high-manganese steels.

OXYGEN IN. Oxygen in Iron and Steel, P. Oberhoffer, H. J. Schiffler and W. Hessenbruch. Foundry Trade Jl., vol. 37, no. 592, Dec. 22, 1927, p. 213. Abstract translated from Archiv fur das Eisenhüttenwesen, July, 1927. As regards influence of oxygen on primary and secondary structure of iron and steel, distinct segregation of crystals was observable after first etching; in overblown steels secondary etching showed a rather coarse grain; influence of oxygen on certain properties of alloy steels; influence of different alloy metals on malleability and redshortness; results of cementation, hardness, decarbonization and forging tests.

RAILS. Means for Improving Steel Rails, Pilz. Metallurgist (Supp. to Engineer), Dec. 30, 1927, pp. 183-185, 6 figs. Abstract of article in Stahl u. Eisen, Oct. 1927, which is review of methods of improving rail steel by means of chemical composition and by heat treatment of rails, with special reference to processes of Sandberg, Neuves-Maison, Huette-Ruhrort-Meiderich and Maximilianshuette; for German State Railways elastic limit in compression of at least 45 kg. and preferably 50 kg. per sq. mm. is stated to be necessary for rail steel to carry engines of 25 tons axle weight.

RIVETS, FOR. Air-Hardening Rivet Steels, H. K. Herschman. U. S. Bur. Standards—Technologic Paper, no. 358, Oct. 19, 1927, pp. 141-169, 19 figs. Study was made of series of alloy steels possessing air-hardening qualities for purpose of determining their applicability for rivets which would have ballistic resistance at least approaching that of armor plate which they joined; steels selected included for most part those of chromium-nickel series and some containing additions of manganese and molybdenum; steels containing total of 4 to 6 per cent of alloying elements, chromium and nickel, were found to produce excellent rivets; however, equally good results were obtained with steels of lower total alloy content by using in addition to chromium and nickel, molybdenum and manganese.

ROMAN DAMASCUS. Roman Damascus Steel (Roemischer Damaststahl), B. Neumann. Archiv fuer das Eisenhuettenwesen, vol. 1, no. 3, Sept. 1927, pp. 241-244, 14 figs. Micrographic examination of Roman double-edged swords showed them to have been made by hammer welding layers of steel of varying carbon content in such a way as to twist layers into V or W shape; subsequently, cutting edges alone were hardened by case hardening process of some kind; general absence of martensite in structure of ancient steel article is discussed and theory advanced to account for it.

ROLLED, FOR ELECTRICAL MACHINERY. Welded Rolled Steel for Electrical Machines, G. Lewinnek. A.E.G. Progress, vol. 3, no. 12, Dec. 1927, pp. 376-379, 9 figs. Replacing some cast iron or cast steel parts of electric machines by those of rolled steel; method of reducing weight of housings of electric machines practiced by A.E.G.; rolled steel rotor body; in vertical shaft 3-phase alternator housing, top and bottom spiders and sole plates of rolled steel; rolled steel bedplate welded on to structural steel of standard cross-section; 2 types of wedge bolts for bolting up 2-part housings; new type of anchoring piece constructed of rolled steel; tests proved that mechanical strength of welded seam practically equal to solid material.

STAINLESS. Stainless Irons and Steels, J. B. Green. Welding Engr., vol. 12, no.12, Dec. 1927, pp. 34-36, 2 figs. Study of corrosion-resisting steel alloys and how changes in composition affect working qualities; description of stainless steels from standpoint of using them in welded articles of manufacture; analyses of various brands of stainless steels.

## STEEL CASTINGS

INTERNAL STRESSES. Shrinkage Stresses in Steel Castings (Schwindungsspannungen in Stahlgusstuecken), H. Malzacher. Stahl u. Eisen, vol. 47, no. 50, Dec. 15, 1927, pp. 2108-2112, 4 figs. Internal stresses due to thermal changes and shrinkage; shrinkage stresses due to resistance of mold; examples of such stresses in cast cylinders and transmission pulley showing compression in thin parts and tension in thick ones.

MOLDING. Steel Foundry Practice (Aus der Stahlgiessereipraxis), L. Treuheit. Stahl u. Eisen, vol. 47, no. 50, Dec. 15, 1927, pp. 2101-2108, 6 figs. Selection and mixing of molding materials, analysis of sands by author's elutriating method; microscopical examinations; comparative cost data on economy of filling and ramming by various methods showing that mechanical methods using special machines are most efficient and most economic. See also Giesserei-Zeitung, vol. 24, no. 24, Dec. 1927, pp. 684-685.

PRODUCTION STATISTICS. Is Steel Capacity Excessive? W. J. Corbett. Foundry, vol. 56, no. 1, Jan. 1, 1928, pp. 29-31 and 39, 7 figs. Comparison of statistics shows marked increase in production of steel castings, but percentage of operation indicates idle facilities.

TESTING. Tension Testing as Applied to Steel Castings. Research Group News, vol. 4, no. 4, Jan. 1928, pp. 164-172, 8 figs. Comments on most commonly used physical test, applied by tension; tensile strength and yield point; advisable precautions in tensile testing; method of casting coupon or rough bar, from which specimen is machined.

WELDING. When Should Steel Castings Be Welded, R. A. Bull. Foundry, vol. 56, no. 2, Jan. 15, 1928, pp. 48-50, 4 figs. Discussion of art as utilized by steel foundrymen and as capable of use by those who buy steel castings; properties of metal formed during welding operation on casting or other part made of steel; what happens to surface adjoining defect when steel casting is welded; methods for testing welds. Abstracted from Research Group News, Oct. 1927.

## STEEL, HEAT TREATMENT OF

AUTOMOBILE PARTS. Ford's and the Heat-Treatment of Steel, J. W. Urquhart. Machy. (Lond.), vol. 31, no. 795, Jan. 5, 1928, pp. 462-463. Present writer, finding heat treatment of several steels at variance from some of best-approved European heat treating practice, offers few comments thereon; manganese-chromium steel much favored; drive shaft material and treatment; front axle treatment; chassis frame members; it is quite evident that steels chosen by Ford are very carefully selected with certain ends in view.

COLD WORKING. Volume Changes in Steel Produced by Cold Working, E. Houdremont and E. Burklin. Iron & Steel World, vol. 1, no. 11, Dec. 1927, pp. 751-756, 3 figs. Discussion of volume change with hardened and cold drawn steels in relation to degree of deformation; no absolute relationship between increase of tensile strength and decrease of density; stress distribution with hardening and cold drawing.

EQUIPMENT. Equipment and Operation of a Heat Treating Plant, M. G. Jewett. Am. Mach., vol. 68, no. 4, Jan. 26, 1928, pp. 171-172, 4 figs. Heat treating plant of Chain Belt Co.; temperature of furnaces regulated by automatic recording controllers; portable quenching tanks equipped with revolving drums and helical conveyors to carry work through water or oil; rotary carburizing machines, rotary tempering furnaces and rotary, continuous heat treating machine; Greene quenching machine; gas for heating; work charged into heat treating machine through spout from balcony directly above and by adjustable buckets; equipment capable of handling 14 tons in and out of furnaces per 24-hr. day.

HARDENING. Hardening Stresses and Hardening Cracks (Haertespannungen und Haerterisse), L. Traeger. Maschinenbau, vol. 7, no. 1, Jan. 1928, pp. 20-23, 10 figs. Analysis of internal stresses due to heat treatment and metallurgical hardening processes; elastic deformations made permanent by annealing process, which increases resistance of material to external stresses; bearing of these observations on hardening practice.

INGOTS. Influence of Heat Treatment on Mild Steel Ingots before Rolling, on Structure and Strength of Material (Einfluss der Waermebehandlung von Weichstahlbloecken vor dem Auswalzen auf Gefuegeausbildung und Festigkeitseigenschaften des Werkstoffes), H. Bitter. Stahl u, Eisen, vol. 48, no. 2, Jan. 12, 1928, pp. 38-39. Investigation prompted by question as to whether cooling of ingots after casting and reheating before rolling, effected improvement in properties of material to be rolled.

TEMPERING. On the Mechanism of Tempering of Steels, T. Matsushita and Kiyoshi Nagasawa. Tohoku Imperial University—Sci. Reports, vol. 16, no. 8, Dec. 1927, pp. 901-913, 10 figs. By means of magnetic, dilatometric and electric resistance analyses, authors have investigated mechanism of tempering carbon steels and obtained following results: during heating, tempering of martensite takes place in two stages, as regards temperature, that is, at 100 to 170 deg. Cent. and 170 to 300 deg. Cent.; product of tempering is not cementite molecules, as has usually been believed to be, but carbon atoms in free state. (In English.)

TUBES. The Effect of Heat Treatment on Cold-Drawn Steel Tubes, F. C. Lea. Eng., vol. 124, no. 3233, Dec. 30, 1927, pp. 831-834, 9 figs. Load strain curves under repeated stress; types of failure; effect of pinch and zink on properties of tubes; cold-drawn tubes after final pass have low limit of proportionality, but strength is much higher than that of normalized material. (Concluded from Dec. 23.)

WIRE. Heat Treatment of Steel Wire, J. D. Brunton. Wire, vol. 3, no. 1, Jan. 1928, pp. 10-12, 3 figs. In order to make structure of steel more uniform throughout piece heat treatment is necessary; wire is annealed with object of softening it so that it can be easily drawn.

## STEEL INDUSTRY

BELGIUM. Steel Prices Low in Belgium. Iron Trade Rev., vol. 82, no. 1, Jan. 5, 1927, pp. 115-116. Reduced trade with far eastern markets affects Belgian exports adversely; record year for production but competition forces prices down; large concerns merging; factors affecting Belgian exports unfavorably; lower costs of production considerably assist in competing against Great Britain; China and Japan poor buyers; national schemes planned; Belgian demand large quotas; tendency toward amalgamation of large concerns.

DEVELOPMENTS, 1927. Widening Sphere of Steel Consumption Marks 1927. Iron Trade Rev., vol. 82, no. 1, Jan. 5, 1927, pp. 44-47, 2 figs. Table of steel demand by main groups, 1922-1927; broadening application of steel to new uses more pronounced in 1927; leading consuming groups, railroad, building, automotive and oil, gas and water industries taking only 57.50 per cent of all finished steel shipments; angle bars, black plates for tinning, and wire products show increase; tables of distribution in gross tons of finished steel output shown by consuming group and individual products; decline in quantity of semi-finished steel materials shipped by mills to other companies for further fabrication.

EASTERN EUROPE. Eastern Europe is Progressing. Iron Trade Rev., vol. 82, no. 1, Jan. 5, 1928, p. 117. Polish and Czech production making rapid strides; export business is regulated; closer working with steel entente expected; Russian output behind schedule; pig iron output and steel production of Poland increased; manufacturers of agricultural implements unable to meet demand; Polish works syndicated; Polish steelmakers have not joined continental steel entente; Hungary adds one furnace; production of iron and steel in Balkan states and Near East continues negligible.

ENGLAND. British Working Against Odds, J. Horton. Iron Trade Rev., vol. 82, no. 1, Jan. 5, 1928, pp. 109-110. Depression follows post-strike revival; foreign invasion continues; tin plate industry low but shipbuilding shows marked improvement; hopes entertained for future; year one of readjustment; shipbuilding is encouraging; iron and steel unemployment in-

creased; decision of manufacturers to give rebate to customers undertaking to purchase only British goods; forge and foundry pig iron exports showed some fluctuation; plate mills need tonnage; burden of heavy railway rates another handicap to British steelmaker; table of British exports in gross tons during 1927.

EUROPE. Competition Acute in Europe, B. Delport. Iron Trade Rev., vol. 82, no. 1, Jan. 5, 1928, pp. 106-108, 1 fig. Prices reach uneconomic level; Great Britain bears heavy costs; continent better equipped to compete; tendency toward amalgamations and price control; continent maintains advance acquired over Great Britain since war; struggle between consumer and producer as to who could obtain best price, and consumer has won; situation 1928 opens unsatisfactory; table of European iron and steel domestic prices in 1927.

EXPORT TRADE. No Retreat from World Steel Markets. Iron Age, vol. 121, no. 2, Jan. 12, 1928, pp. 135-136. Banker's view that exports be reduced vigorously refuted on ground of international relations, domestic economy and merchant marine; European steel exports expanding rapidly; American sales made on quality rather than price; much study given to technical problems; heavy steel exports necessary for efficient merchant marine; exports of other industries compete with Europeans; repercussions of 5 per cent steel curtailment.

FRANCE. French Industry Resists Crisis, J. Leon. Iron Trade Rev., vol. 82, no. 1, Jan. 5, 1928, pp. 113-114. Home industries depressed by credit restriction and reduced purchasing power; production maintained and exports rise but prices unprofitable; coming elections darken outlook; producers seek export trade; activities of automobile manufacturers considerably reduced; makers of agricultural machinery experienced serious crisis; building trades depressed; downfall of prices given in accompanying price tables; 1926 profits assist industry; coke prices forced down.

GERMANY. Active Year for German Steel, E. H. Regensburger. Iron Trade Rev., vol. 82, no. 1, Jan. 5, 1928, pp. 111-112. Heavy domestic business makes up for export losses; real progress made in plant efficiency; exports drop while imports increase; coal industry less flourishing; increases of wages and taxation resulted in heavier costs of production; government took measures to prevent selling prices from exceeding certain limits; Germany loses export market; may lose neglected markets; ore imports make gain.

IMPROVEMENTS. Some Improvements in Steel Trade Forecast for 1928, L. H. Haney. Iron Age, vol. 120, no. 1, Jan. 5, 1928, pp. 10-13 and 109, 5 figs. Greater volume and enhanced prices anticipated; general business conditions; further adjustments needed; summary of year's developments; improvement in steel seems certain.

ITALY. Italy is Planning for Future. Iron Trade Rev., vol. 82, no. 1, Jan. 5, 1928, p. 116. National production officially encouraged; industrial depression accompanies lira appreciation; iron ore resources and hydroelectric plant being developed; inspired by strong leadership, Italy is striving more to develop national industries and restrict importations; manufacturers still may have to face period of depression; gradual readaptation to present monetary conditions will bring return to normal; iron imports restricted; electrical processes of manufacture of iron and steel widely applied.

JAPAN. Japan a Growing Producer of Steel, G. S. Herrick. Iron Age, vol. 120, no. 1, Jan. 5, 1928, pp. 55-59, 1 fig. Industry, quarter century old, is supplying more than half of domestic requirements in finished steel products; Seitetsu Jo leading producer; system of subsidies to steel producers; iron ore resources limited; sand ore may be used for sponge iron; many small mills; sheet, nail, and wire capacity expanded; plants in Manchuria and Chosen; tables of open-hearth and rolling mill capacity, wire nail and wire production.

PROBLEMS. Better Marketing is Steel Need. Iron Age, vol. 120, no. 1, Jan. 5, 1928, pp. 62-64, 2 figs. Opinions of steel sales executives; laxity has developed in merchandising of steel; stockholders' rights to fair return ignored; contracts should be fixed as to price and tonnage; firm or binding contracts would improve steel situation; small-lot sales by mills blamed for some of industry's ills; concessions to large buyers soon reflected in all sales; no price recognition of more exacting steel specifications; steel-plate contract has become only loose protection; problems of buyer should be considered in sales policies.

PROGRESS AND PROSPECTS. Steel Trade Now Looks to 1928 to Compensate for Some of the Recession of 1927—Forces That May Make for Greater Market Stability. Iron Age, vol. 120, no. 1, Jan. 5, 1928, pp. 1-5 and 110, 2 figs. Possible compensations; consolidation tendency more pronounced; little new capacity building; hard year for pig iron producers; fabricators' orders more but shipments less; scrap had small fluctuations; efforts to steady prices; exports increase while imports decrease.

RUSSIA. Iron and Steel Economics in Soviet Russia, H. T. Freyn. Blast Furnace and Steel Plant, vol. 16, no. 1, Jan. 1928, pp. 1-3. Author, who is most intimately acquainted with conditions in Russia, gives authentic information in regard to rehabilitation of steel industry in that country.

STATISTICS, 1927. By-Product Coke Oven Expansion is Feature of 1927 Construction, J. D. Knox. Iron Trade Rev., vol. 82, no. 1, Jan. 5, 1928, pp. 61-63. Iron and steel industry on low plane compared with former construction programs; rolling mill construction failed to command a favorable position; extension in by-product coke industry stamps 1927 as best year since 1920; two basic open-hearth furnace units scheduled; stack construction lacking; new units installed; tables of equipment completed or building during 1927 and rolling mills completed or building during 1927.

## STEEL MANUFACTURE

IMPROVEMENTS. Effect of Industrial Progress on Steel Production. Research Group News, vol. 4, no. 4, Jan. 1928, pp. 160-163. Improved manufacture of steel parts; improvement has not by any means been restricted to making metal in furnace, but has attended many other highly important

operations required for production of finished parts, some such operations being of much greater significance as to performance of piece than is melting of steel; development of special steels; relationship of research to quality in steel.

METHODS. Modern Methods of Making Steel. S. African Min. and Eng. Jl., vol. 38, no. 1891, Dec. 24, 1927, pp. 457-459, 2 figs. Producer gas for heating; Bessemer process for making steel is entirely different from open-hearth method, and consists of blowing cold air through liquid iron from blast furnace; open-hearth method is more independent of class of raw material used; more time is available, and it is possible by its use to obtain final product whose production would be impossible with Bessemer process. (Continuation of serial.)

METHODS. Notes Concerning the Manufacture of Steel (Notas sobre la fabricacion de aceros), G. Nunez. Revista Minera Metalurgica y de Ingenieria, vol. 79, no. 3103, Jan. 8, 1928, pp. 14-18. General discussion of rustless steel, hard steel, forged and rolled steel, invar steel, and finally standardization of various kinds of steels.

## STEEL WORKS

PULVERIZED COAL IN. Auxiliary Fuel with Blast Furnace Gas, F. H. Daniels. Blast Furnace and Steel Plant, vol. 16, no. 1, Jan. 1928, pp. 52-55, 3 figs. Powdered coal is finding increasing favor as primary and secondary fuel in conjunction with gas; description of methods of burning coal and coke braize.

## STRUCTURAL STEEL

SAFETY AND STRENGTH. Factors of Safety and Quality of Material, W. H. Riddlesworth. Engineer, vol. 144, no. 3755, Dec. 30, 1927, pp. 748-749. Introduction of special steels having an elastic limit considerably higher than that for ordinary mild steel, affords reason for re-examination of two questions in connection with structural design, namely, factor of safety and strength properties; indicates considerations which should govern magnitude of safety factor and its relation to appropriate strength property of material.

## TANTALUM

PROPERTIES AND USES. Tantalum, F. G. Palmer. Metallurgist (Supp. to Engineer), Dec. 30, 1927, pp. 185-186. It is silvery white in color, can be drawn, hammered, rolled, hardened, polished, and punched in cold state; it is exceedingly resistant to attack by majority of corrosives; there are many uses for tantalum in manufacture of surgical and dental instruments.

## TUBES

COPPER, SEAMLESS. Manufacturing Seamless Copper Tubes Electrolytically, J. Silberstein. Metal Industry (N. Y. ), vol. 25, no. 12, Dec. 1927, pp. 487-488. New German process for making smooth tubes of large diameter by electrolysis.

STEEL, AIRCRAFT. Inspection of Aircraft Tubing, H. C. Knerr. Iron Age, vol. 121, no. 3, Jan. 19, 1928, pp. 201-203, 3 figs. Results of experiments show that mild carbon can be separated from alloy steels after normalizing by testing individually for Rockwell hardness; normalizing range is wide, variations in temperature between 1490 and 1660 deg. Fahr. having little effect on hardness or tensile values; test is rapid, inexpensive and can be performed by relatively unskilled operator; it has been approved by Navy Department, and is being applied to every tube of chrome-molybdenum steel No. 4130X, before shipment by Summerill Tubing Co.

## WELDING

FUSION. The Most Important Thing in Welding, S. W. Miller. Domestic Eng. (Chicago), vol. 121, no. 11, Dec. 10, 1927, pp. 26-27. Considers that procedure involves everything that has to do with making of an article; essential to procedure are (1) design (2) materials (3) methods (4) operators (5) supervision (6) tests.

OIL FIELDS. Welding Material in the Oil Fields. West. Machy. World, vol. 18, no. 11, Nov. 1927, pp. 534-536 and 542, 18 figs. Building up and hard facing fishtail bits and rotary disks.

PIPE FITTINGS. Templets for Welded Pipe Fittings. Domestic Eng., (Chicago), vol. 121, no. 8, Nov. 19, 1927, pp. 18-20 and 72, 10 figs. Brings up question of pipe patterns or templets and gives suggestions; elements of templet construction; development of pipe surface; templet for 45-degree intersection; metal templets.

PRESSURE VESSELS. Welding Pressure Vessels, T. M. Jasper. Welding Engr., vol. 12, no. 11, Nov. 1927, pp. 35-37, 8 figs. Examples of products in service which show dependability of welding and a few tests to show sort of research work back of these products.

PROCESSES. Welding in Mechanical Construction (La soudure autogéne dans la construction mecanique), E. Delamarre. Technique Moderne, vol. 20, no. 1, Jan. 1, 1928, pp. 41-48, 27 figs. Treats of various processes of welding and their application; blowpipe, electric-arc, electric resistance; material necessary for various processes; net cost of welding; charts giving costs of various welding methods.

STEEL CASTINGS. What Are the Justifiable Uses of Welding in Production of Steel Castings? R. A. Bull. Iron Trade Rev., vol. 81, no. 24, Dec. 15, 1927, pp. 1475-1477 and 1488, 4 figs. Deals with policy on welding adopted by group of electric steel foundries.

STRUCTURAL STEEL. Survey of Existing Test Data by Structural Steel Welding Committee of American Bureau of Welding. Am. Welding Soc.—Jl., vol. 6, no. 11, Nov. 1927, pp. 8-14. Purpose of proposed tests is to secure data showing ultimate or breaking strength of joints, of type suited to structural steel work, when welded under uniform conditions by any available process, gas or electric.

TANKS. Better Gas Welds in Light Tanks, H. J. Grow. Welding Engr., vol. 13, no. 1, Jan. 1928, pp. 25-28, 3 figs. Attention to mechanical details of procedure will remove many causes of defective seams in thick sheet steel; simple butt weld in cylindrical shell can be made in numerous ways, with varying degrees of appropriateness depending on manufacturing conditions and arrangements.

# News of the Society

## THE SEMI-ANNUAL MEETING AT MONTREAL

THE first general meeting of the American Society for Steel Treating for the year 1928 was held in Montreal, Canada, on February 16 and 17. This winter meeting of the society, better known as the semi-annual meeting, was the first general meeting ever held by the society outside of the United States. A goodly number of members and guests attended this 2-day session of technical papers and plant inspection trips. The spacious Mount Royal Hotel was the headquarters for this meeting and provided its splendid facilities to make the stay of our members and guests both profitable and enjoyable.

Inasmuch as all of the fourteen papers presented before this meeting will be published in early issues of TRANSACTIONS no attempt will be made at this time to abstract the papers nor to report the discussions which took place. In order, however, that those who were unable to attend the meeting may be informed of the activities of this meeting, the schedule of events as they occurred are published herewith.

On Wednesday, February 15, the officers and directors of the society held an all-day executive session, the minutes of which will be published in the April TRANSACTIONS. Likewise the Publication Committee and the Recommended Practice Committee held business meetings for the purpose of discussing matters of importance confronting each committee in the conduct of its duty.

The complete program of events and the papers presented is as follows:

### THURSDAY, FEBRUARY 16

**Morning Session**—Piazza Room

9:00-10:30 A. M.—Registration.

Technical Session

Prof. Alfred Stansfield, Chairman

10:30-11:20 A. M.—*Crystal Micrography*—R. G. Guthrie, Peoples Gas Light & Coke Co., Chicago, and J. Fletcher Harper, Allis-Chalmers Mfg. Co., Milwaukee.

11:20-12:00 A. M.—*Steels for Case Nitrification*—A. B. Kinzel, Union Carbide and Carbon Research Laboratories, Long Island City, N. Y.

**Afternoon Session**—Piazza Room

R. M. Bird, Chairman

2:00- 2:40 P. M.—*Some Failures of Locomotive Parts and an Examination of their Structures under the Microscope*—F. H. Williams, Canadian National Railways, Montreal.

2:40- 3:10 P. M.—*X-Rays and the Constituents of Stainless Steel*—E. C. Bain, Union Carbide and Carbon Research Laboratories, Long Island City, N. Y.

3:10- 3:40 P. M.—*The Manufacture of Stainless Steel Castings in the Various Industries*—V. T. Malcolm, Chapman Valve Mfg. Co., Indian Orchard, Mass.

3:40- 4:10 P. M.—*Hardness Testing*—H. M. German, Universal Steel Co., Bridgeville, Pa.

**Evening Session**—Nightingale Room

President F. G. Hughes, Chairman

8:00- 8:45 P. M.—*Heat Treatment of Forgings and Castings for Selective Directional Adjustment of Residual Stresses*—W. J. Merten, Westinghouse Electric and Manufacturing Co., East Pittsburgh.

8:45- 9:30 P. M.—*Medium Carbon Pearlitic Manganese Steels*—Jerome Strauss, U. S. Navy Yard, Washington, D. C.

## FRIDAY, FEBRUARY 17

**Morning Session**—Piazza Room

A. H. d'Arcambal, Chairman

10:00-10:40 A. M.—*Effects of Antimony, Arsenic, Copper and Tin in High Speed Tool Steel*—H. J. French and T. G. Digges, Bureau of Standards, Washington, D. C.

10:40-11:20 A. M.—*Some General Thoughts on Fusion Welding*—S. W. Miller, Union Carbide and Carbon Research Laboratories, Long Island City, N. Y.

11:20-12:00 A. M.—*Types of Failure of Steel*—Robert Job, Milton Hersey Co., Ltd., Montreal.

**Afternoon Session**

1:30 P. M.—Choice of Plant Inspection:

(1) Canadian Steel Foundries, Ltd., Longe Pointe Plant, manufacturing locomotive frames, railroad castings and hydroelectric castings; and Canadian Vickers, Ltd., the largest Canadian producers of airplanes.

(2) Dominion Engineering Works, Ltd., and Dominion Bridge Co., Ltd., manufacturing largest paper machinery on this continent; also oil stills, tank work and heavy construction work.

**Evening Session**—Piazza Room

J. R. Adams, Chairman

8:00- 8:40 P. M.—*Alloy Steel for Boiler Construction*—Charles McKnight, International Nickel Co., New York City.

8:40- 9:20 P. M.—*The Effect of Heat Treatment on the Properties of Chromium-Molybdenum Sheet Steel*—F. T. Sisco and D. M. Warner, Wright Field, Dayton, Ohio.

9:20-10:00 P. M.—*A Note on the Hardness and Impact Resistance of Chromium-Nickel Steel*—B. F. Shepherd, Ingersoll-Rand Co., Phillipsburg, N. J.

# News of the Chapters

## SCHEDULED MEETING NIGHTS OF CHAPTERS

For the convenience of visiting members, those chapters having scheduled meeting nights are listed below.

BOSTON—First Friday, H. E. Handy, secy., Saco-Lowell Shops, Lowell, Mass. Phone, Lowell 4050.

Apr. 6—Pyrometry ..... V. O. Homerberg
May 4—Stainless Iron and Stainless Steel ..... V. O. Homerberg

BUFFALO—Fourth Friday. F. L. Weaver, secy., American Radiator Co., Bond Plant. Phone, Riverside 1770.

CANTON-MASSILLON—No schedule of meetings as yet received. Robt. Sergeson, secy., Central Alloy Steel Corp., Canton, Ohio. Phone 5121.

CASE GROUP—No schedule of meetings as yet received. J. M. Burns, secy., Case School of Applied Science, Cleveland. Phone, Garfield 6680.

CHICAGO—Second Thursday, with exception of March 6. J. A. Comstock, secy., Room 1724 Peoples Gas Bldg. Phone, Wabash 6000, Local 364.

Mar. 6—Nickel Cast Iron ..... P. D. Merica
Apr. 12—Manufacture of Cold Drawn Steel ..... F. R. Bonte

CINCINNATI—No schedule of meetings as yet received. W. J. Lange, secy., Robert J. Anderson, Inc.

CLEVELAND—Third Friday. J. S. Ayling, secy., Case Hardening Service Co. Phone, Atlantic 0293.

Mar. 16—Brass and Bronze Alloy ..... C. H. Bierbaum
Apr. 20—Metal Stamping ..... G. L. Kelley
May 18—Social Meeting.

COLUMBUS—Third Tuesday, with exception of Feb. 14. G. D. Moessner, secy., Buckeye Steel Castings Co. Phone, Garfield 0600.

Mar. 20—High Speed Steels ..... J. V. Emmons
Apr. 17—Forgings ..... Harold Wood
May 15—Open-Hearth Practice ..... W. R. Flemming

DAYTON—No schedule of meetings as yet received. F. M. Reiter, secy., Dayton Power & Light Co.

DETROIT—Third Monday. Jos. G. Gagnon, secy., Hudson Motor Car Co. Phone, Lenox 3232.

FORT WAYNE—Paul Renfrew, secy., S. F. Bowser & Co. Phone, Harrison 2341.

Feb. —Procedure of Correct Hardening ..... Jordan Korp
Mar. —Carburizing and Heat Treatment ..... B. F. Shepherd
Apr. —Nickel-Chromium Alloy in Gray Iron ..... D. M. Houston
May —Shop Equipment and Shop Kinks ..... H. B. Northrup

GOLDEN GATE—Second Wednesday. S. R. Thurston, secy., Bethlehem Shipbuilding Corp., San Francisco.

Mar. 14—Symposium and Discussion by Members on the Physical Properties of Steel. Their Significance and Their Relations. Bases for the Selection of Carbon and Alloy Structural Steels for Specific Purposes.
Apr. 11—Joint Meeting with the American Welding Society—Subjects: Properties of Welds at High Temperature ..... K. V. Laird
Properties of Carbon and Alloy Steels at High Temperatures.
May 9—The Hardness of Metals, Methods of Testing and What They Test. Compariscon of the Wear Resistance of Different Metals Under Different Conditions of Heat Treatment.
June 13—Heat Treatments of Nonferrous Alloys, Their Purpose and Their Significance.
Moving Picture—The Story of Copper.

HARTFORD—Second Tuesday. Henry I. Moore, secy., Firth Sterling Steel Co. Phone, 6-5554 Hartford.

Mar. 13—Heat Treatment of Aluminum Alloys .....R. S. Archer
Apr. 10—Manufacture of Automotive Alloy Steels .....E. C. Smith
May 8—Manufacture of Malleable Iron.....H. A. Schwartz
June 8—Eighth Annual Banquet.

INDIANAPOLIS—Second Monday. James S. Marlowe, secy., 606 State Life Bldg. Phone, Riley 3724.

LEHIGH VALLEY—No schedule of meetings as yet received. H. V. Apgar, secy., Ingersoll-Rand Co., Phillipsburg, N. J. Phone 977.

LOS ANGELES—Second Thursday. H. V. Ruth, secy., Ducommun Corp. Phone, TR. 0621.

MILWAUKEE—Second Monday. Knight Charlton, secy., Bucyrus Co. Phone 1.

MONTREAL—No schedule of meetings as yet received. D. G. MacInnes, secy., Apt. 35, 376 Claremont Ave., Westmount, Montreal.

NEW HAVEN—Second Thursday, with the exception of June 15. F. E. Stockwell, secy., Standard Oil Co. of New York. Phone, Beacon 1520, Pioneer 9940.

Mar. 8—Manufacture, Use and Heat Treatment of Stainless Steel....
.....C. E. MacQuigg
Apr. 12—High Speed Steel .....J. P. Gill
May 10—Place of Nonferrous Metals in Industry.....
.....W. G. Price and Alvan L. Davis
June —Annual Frolic—Details and date will be announced later.

NEW YORK—Second Monday. I. N. Holden, Jr., secy., E. W. Bliss Co. Phone, Sunset 9000.

NORTH-WEST—No schedule of meetings as yet received. Alexis Caswell, secy., Manufacturers' Assn. of Minneapolis.

Mar. —Open
Apr. —Molybdenum Steels .....Dr. F. C. Langenberg
May —Gears and Gear Steel .....E. C. Smith

NOTRE DAME—Second Friday. Frank J. Mootz, secy., Notre Dame University. Phone, Lincoln 1121.

PHILADELPHIA—Last Friday. A. W. F. Green, secy., 407 Shoemaker Rd., Elkins Park, Pa. Phone, Melrose 4542-M.

Mar. 30—Case Hardening with Particular Attention to Nitrogenizing
Apr. 27—General Melting Practice, Influence of Crystallization and Cooling on the Commercial Application of Metals.

PITTSBURGH—First Thursday. H. L. Walker, secy. Box 521, North Side Station.

RHODE ISLAND—Third Wednesday. C. G. Peterson, secy., 100 Weybosset St., Providence. Phone, Gaspee 6233.

ROCHESTER—Second Monday. Irving C. Mathews, secy., Eastman Kodak Co. Phone, Glenwood 1300.

Mar. 12—Dr. Jekyll and Mr. Hyde of Metallurgy.....T. S. Fuller
Apr. 9—Die Castings .....Sam Tour
May 14—Business Meeting—Election of Officers

ROCKFORD—Second Friday. O. T. Muehlemeyer, secy., 700-702 Race St. Phone, Forest 447.

SCHENECTADY—Third Tuesday. J. G. Hicks, secy., American Locomotive Co. Phone, 2-4900-Ext 44.

Mar. 20—Steels at Elevated Temperatures.....H. J. French, F. B. Foley

SOUTHERN TIER—Third Monday, with exception of Apr. 23. Walter H. Odgen, secy., 11 Rotary Ave., Binghamton, N. Y. Phone, Bingham 2425.

SPRINGFIELD—Third Monday, with exception of Mar. 21, Apr. 25 and May 23. E. L. Woods, secy., Springfield Gas Light Co. Phone, 5-3900.

ST. LOUIS—Third Friday. C. C. Werscheid, secy., Colonial Steel Co. Phone, Garfield 1263.

SYRACUSE—Second Tuesday. S. P. Peskowitz, secy., Halcomb Steel Co. Phone, 3-1231.

Mar. 13—Carburizing and Heat Treatment of Carburized Objects.....B. F. Shepherd
Apr. 10—Flow of Metals in Forging .....J. H. Nelson

TORONTO—No schedule of meetings as yet received. A. Lowry, secy., 450 Willard Ave.

TRI CITY—No schedule of meetings as yet received. George A. Uhlmeyer, secy., People's Power Co., Moline, Ill.

WASHINGTON-BALTIMORE—No schedule of meetings as yet received. H. K. Herschman, secy., Bureau of Standards.

WORCESTER—Mar. 14—no further meeting dates as yet scheduled. C. G. Johnson, secy., Worcester Polytechnic Institute. Phone, P110.

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## STANDING OF THE CHAPTERS

DURING the month of January there were 160 new and reinstated members, while 99 were lost through arrears, resignations and deaths, leaving a net gain for the month of 61 members. The total membership of the Society on February 1, 1928, was 4893.

Membership standing of the society as of February 1, 1928, is as follows:

| GROUP I | | GROUP II | | GROUP III | |
|---|---|---|---|---|---|
| 1. Detroit | 483 | 1. Hartford | 135 | 1. Tri-City | 86 |
| 2. Chicago | 445 | 2. Dayton | 134 | 2. New Haven | 81 |
| 3. Pittsburgh | 371 | 3. Milwaukee | 122 | 3. Washington | 77 |
| 4. Philadelphia | 326 | 4. Golden Gate | 118 | 4. Worcester | 76 |
| 5. Cleveland | 316 | 5. Lehigh Valley | 115 | 5. Rockford | 62 |
| 6. New York | 301 | 6. Los Angeles | 112 | 6. Columbus | 59 |
| 7. Boston | 262 | 7. Canton-Mass. | 108 | 7. Providence | 57 |
| | | 8. Indianapolis | 104 | 8. Rochester | 55 |
| | | 9. St. Louis | 95 | 9. Toronto | 52 |
| | | 10. Cincinnati | 93 | 10. Southern Tier | 48 |
| | | 11. Syracuse | 88 | 11. Fort Wayne | 41 |
| | | 12. Buffalo | 69 | 12. Schenectady | 41 |
| | | 13. Montreal | 68 | 13. Springfield | 37 |
| | | 14. North-West | 53 | 14. Notre Dame | 27 |

GROUP I—All chapters in this group have the same position they had last month. However, Chicago with a net gain of 15, is now only 38 members behind Detroit. Pittsburgh had a net gain of 11, followed by Cleveland and Boston with gains of 6 and 5 respectively.

GROUP II—The Society welcomes this month a new addition to this group by a transfer at their own request of Los Angeles from Group III. Last month Los Angeles had a net increase of 17 new members, bringing their total up to 112. Los Angeles by this transfer to Group II occupies position No. 6, 3 behind Lehigh Valley in 5th place; 6 from Golden Gate in 4th and 10 behind

Milwaukee in 3rd. It will be interesting to note the progress Los Angeles will make in the new group.

Last month Dayton headed Group II with a membership of 133. Dayton gained only one while Hartford gained 8, which placed them in first position with a margin of 1. Golden Gate with a gain of 2 passed Lehigh Valley who suffered a loss of 2. St. Louis with a gain of 3 passed Cincinnati with a gain of 1; while Montreal having suffered a loss of 4 has been displaced by Buffalo, from the position held last month. North West added 4 new members.

GROUP III—By the transfer of Los Angeles to Group II, Tri City and New Haven are now going to fight it out again for position 1 in this group. The honor this month goes to Tri City although they suffered a net loss of 5 last month. Washington with a gain of 6 passed Worcester with a gain of 3, going into 3rd position. Rockford maintains its same position. Rochester with a loss of 4 and Toronto with a loss of 3 slipped down the ladder and were replaced by Columbus and Providence. Southern Tier, Fort Wayne and Schenectady hold their old positions. Springfield had a gain of almost 10 per cent in membership last month.

## CINCINNATI CHAPTER

The regular January meeting of the Cincinnati Chapter of the American Society for Steel Treating was held at the Engineers Club on Thursday evening, January 5, 1928. O. Z. Klopsch of the Wolverine Tube Company of Detroit was the speaker of the evening, his subject being "Quenching".

In his talk Mr. Klopsch outlined the work on the study of cooling rates in various quenching media, with which he had been so closely associated while at the Bureau of Standards. He showed how it is now possible to calculate the cooling rate at the centers of rounds, spheres, and plates when quenched in various quenching media, and from various quenching temperatures, and pointed out how this could be used as a basis for further work on the study of temperature distribution in steel samples during quenching. He then discussed quenching media in general, showing what physical properties of liquids are important in influencing the cooling rate which they can impart to steel on quenching.

Dr. George M. Enos, of the University, spoke briefly on the subject of ferrite, this being the first of a series of ten minute talks on the micro-constituents of steel

*Roy O. McDuffie.*

## CLEVELAND CHAPTER

The regular meeting of the Cleveland Chapter was held in the Cleveland Engineering Society Rooms, Carnegie Hall, Friday evening, January 20, 1928.

Reports from the various chairmen were heard and approved.

The speaker, Horace C. Knerr, consulting metallurgist, delivered an extremely interesting paper on "Aircraft Metallurgy". The talk was supplemented with slides. Mr. Knerr discussed the choice of materials, specification for purchasing and inspection of same, processes of machining, forming, riveting, welding, brazing and corrosion preventions. One of the high points was the absolute need of metallurgical control throughout.

Despite the very bad weather over one hundred and fifty members and

guests were on hand and were well repaid by the excellent talk. The dinner preceding the meeting again proved popular with about thirty-five members present. This dinner is always good, reasonable, and offers an excellent opportunity to become better acquainted with fellow members.

The Question Box feature lately adopted for discussion of questions proved interesting and promises to become an important part of our meetings.

Questions should be mailed to C. G. Shontz, c/o Eaton Axle & Spring Co., E. 65th & Central Ave. To be answered intelligently they should be accompanied by as much detail as possible, and in order to be answered at the next meeting should be in his hands at least one week previous to the regular meeting.

*J. S. Ayling.*

## DAYTON CHAPTER

The regular monthly meeting of the Dayton Chapter was held Wednesday evening, January 25, 1928, at the Dayton Engineer's Club. Thirty members met for dinner at 6:30, and afterward listened to an interesting talk by E. E. Hummerich of the National Cash Register Co., on "Fine Finishes for Metal". Everyone is familiar with the beautiful walnut, oak and mahogany finish on cash registers, but few of the steel men present had any idea how these finishes were applied.

Mr. Hummerich told of the care necessary in preparing the spot-welded cabinet for finishing. The next operation is the application of the ground color; this is followed by baking, sanding, and graining operations. The imitation wood finish is then put on by a photoengraving process. The difference in colors, for example, brown mahogany, red mahogany or oak is due to combining different colored inks and ground colors.

After the photoengraving process the cabinets are lacquered and dried. Several coats are necessary to give the fine finish. The talk ended by a discussion of the relative merits of enamels and lacquers. Mr. Hummerich stressed the advantage of baked enamel for the first coats and of lacquer for the last coats.

The regular meeting started at 8 p. m. with an educational feature entitled "Pearlite" by R. G. Rogers, heat treatment superintendent of Delco-Remy Corporation. This short educational talk was illustrated by photomicrographs.

The principal speaker of the evening was R. S. Poister, metallurgical engineer of the Electro Metallurgical Corporation, Pittsburgh, who discussed alloy steels. Mr. Poister's paper was confined to silicon, manganese and chromium steels and was one of the most comprehensive and detailed discussions that it has ever been our privilege to hear. He began with the manufacture of the ferro alloy, the various grades of alloys made and their effect when added to molten steel, and then took up in succession the commercially important steels in which the alloy discussed was the predominating element. The speaker gave in detail the properties and uses of the high silicon electrical steels, the silico-manganese steels, and the low and high manganese steels. In the chromium series all of these steels were comprehensively discussed from the low chromium to the high chromium stainless series. The chromium steels were described from the standpoint of their properties, response to heat treatment, value and

uses. In the discussion that followed several members expressed their appreciation of Mr. Poister's interesting paper. *F. T. Sisco.*

## DETROIT CHAPTER

The first meeting for 1928 of the Detroit Chapter of the American Society for Steel Treating was held January 16 in the General Motors Bldg. The coffee talk was given by Mr. Belknap of the University of Michigan and concerned Prof. Hobbs' expeditions to Greenland. The information was conveyed by visual means, a number of colored slides being used and three reels of motion pictures were shown.

The speaker of the evening was W. M. Pierce of the New Jersey Zinc Company, who spoke on "Zinc and its Alloys." The subject was divided into three main headings, the first of which was rolled zinc. Zinc is rolled in ribbons from ⅛ to 0.006 of an inch thick. Sheet zinc can be had in almost any thickness. There are several grades of zinc which are rolled and the difference is largely due to the presence of cadmium. Cadmium enters into solid solution in zinc which stiffens it and makes it more brittle. Zinc is more ductile at room temperature or slightly above and working of zinc can best be done at 100 degrees Fahr. Zinc is self annealing at room temperature.

The second division of zinc and its alloys had to do with galvanizing. This Mr. Pierce held in abeyance and considered zinc die cast alloys, his third subdivision. Some time ago there was a well founded dislike to zinc base die castings. This was because in time the alloy weather-cracked and the casting wore out. A scientific investigation was made and it was found that this disintegration was due to the presence of small amounts of aluminum in the alloy.

The deterioration in zinc-base alloys containing aluminum was due to the formation of an easily attacked eutectic and grain boundaries. Fortunately there are other metals which counteract this effect as copper and magnesium. An alloy of 4% aluminum, 3% copper, 0.10% mangesium and the balance zinc with a low lead and cadmium content does not crack or lose strength with aging to any marked degree. This alloy is not recommended for handling live steam but for ordinary uses of die castings is most satisfactory. Tensile strength of the die cast metal is about 47,000 pounds per square inch. *J. G. Gagnon.*

## GOLDEN GATE CHAPTER

The January meeting was held at the Engineers' Club, San Francisco, on Wednesday, January 11, 1928.

After a brief business session, Chairman Dr. W. J. Crook introduced W. H. Eisenman, national secretary, who told us of some of the progress and plans of the national office. "Bill" went somewhat into detail regarding the plans for the "Western Metal Congress" to be held in Los Angeles, January, 1929, and said he felt that the Golden Gate Chapter would offer every co-operation. He is right.

"Problems of Ordnance Design" by Major R. W. Pinger, U. S. A. was the first technical paper presented. The Major's talk, accompanied by lan-

tern slides, was of particular interest. He pointed out the continual strife for supremacy between projectile and armor, and brought out the fact that as soon as a superior armor plate was put into use, special and heat treated steels were required to withstand the pressures generated within the gun firing the projectile. Slides were shown of various forms of cannon—how the modern weapon is built up, tanks, bombs, etc.

Major Pingers' paper was followed by a talk on "Special Steels Used by the Navy" presented by Captain C. S. McDowell, U. S. N.

Captain McDowell brought out the fact that the three principal considerations in modern battleship construction were—offensive, defensive and speed. These three have been nicely balanced by the aid, in many instances, of heat treated and special alloy steels. The Captain called attention to new demands for protective decks to withstand air assaults, and noted as one of the annoying conditions the Navy was endeavoring to solve, and in which some degree of success had resulted, that of corrosion at and near the water line.

Dr. W. J. Crook in a short talk stressed the fact that anyone with engineering training, and a knowledge of metallurgy could well qualify as a reserve officer in the ordnance division of the Army and Navy, because, said the doctor, the metallurgical problems met with in this branch of the service were almost identical with conditions which obtain in the commercial practice. Specification as to annealing, normalizing, tempering, hardening, etc., being the same as those with which we are familiar.

Major Hayes of the Army, Presidio of San Francisco, showed a reel of animated movies which allowed us to visualize the manner by which extreme shock and rebound is taken up when large coast defence guns are discharged. This show was extremely interesting, and its end concluded the evening.

The dinner preceding the meeting was attended by fifty-five members and guests, and perhaps a score more were present at the meeting.

*S. R. Thurston.*

## INDIANAPOLIS CHAPTER

The regular monthly meeting of the Indianapolis Chapter was held on the night of January 9, at which time Dr. John A. Mathews, vice-president of the Crucible Steel Co. of America, was the principal speaker. Dr. Mathews' subject was, "The Importance of Chromium in Alloy Steel Metallurgy," and the subject was lucidly presented by its author. Following the presentation of the paper, a comprehensive and interesting discussion of many of the interesting facts brought out by Dr. Mathews took place.

In addition to the paper presented by Dr. Mathews, short talks were given by W. H. Atkins and John A. Keller. The Indianapolis Chapter is much indebted to Harry C. Atkins, president of the E. C. Atkins Company, saw manufacturers, who has been very much interested in the welfare of the Indianapolis Chapter and has given his assistance to the Chapter in many ways. Mr. Atkins has recently been appointed a member of the National Finance Committee of the Society.

Professor John A. Keller, of Purdue University, brought to our attention his plan for carrying on the extension work at the University, giving the same lectures and instructions that he has devoted his time to recently in Ohio and

Chicago territory for the Society. This meeting was well attended, there being more than 100 members and guests present. *James S. Marlowe.*

## NEW HAVEN CHAPTER

In co-operation with the Department of Engineering of New Haven College, the New Haven Chapter has arranged for a short course in practical metallurgy, which, through the courtesy of Yale University, is being conducted in one of the Yale buildings.

W. Paul Eddy, Jr., a graduate of Syracuse University and at present metallurgist at the Geometric Tool Company, has consented to teach the course. With his training and background of practical steel treating, the course will be easily followed by men with or without previous book knowledge of the subject.

The course as planned will cover the general manufacture, use, inspection and heat treatment of metals. Particular attention is to be given to the constitution and properties of steels, and to the changes occasioned in these by heat treating and by hot or cold working. The particular uses of all types of steel and iron are fully discussed, the advantges of each being carefully studied.

The course started on February 6, 1928 and will continue for 17 weeks, classes meeting one night a week (Monday). A certificate of proficiency in practical metallurgy will be awarded to those who satisfactorily complete the course.

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The New Haven Chapter started the new year off true to style with a dinner at the Hotel Bishop with about 20 in attendance. They say that when a man's stomach is satisfied, his thoughts turn elsewhere, so Tom Chamberlain and Buddy Aurand got on a clue and with the aid of Fred Dawless the scent was followed and the game captured. Well it was well worth the effort, thanks to our good friend Dawless.

The meeting started promptly at 8 o'clock due to the fact that our speaker had to catch an early train. The chairman of the program committee, Harold Fish, is surely to be congratulated in securing as a speaker, George A. Richardson, manager of the technical publicity department of the Bethlehem Steel Company who gave a mighty fine talk illustrated by some very late moving pictures. The evening was one well spent and it was the opinion of the members present that the absentees missed something well worth while. The program for the entire year is of the same caliber, so avail yourselves of what the program committee has arranged and you will find yourself well repaid. We were indeed sorry that Mr. Richardson had to leave early as it left very little time for questions but we are hoping sometime that he will pay us a return call.

The attendance prizes donated by Fred J. Dawless of the Crucible Steel Company and Professor Arthur Philipps of Yale University were won by Mr. Russell Young of the O. K. Tool Company and Mr. John F. Sargent of the R. Wallace & Sons Mfg. Company. Again it pays to be among those present.

The writer failed to see the smiling countenance of Major Bellis. What's the matter, major, are you froze up down in Branford? We also missed the Porter family from Bridgeport and hope that now as Spring is approaching, they will again be counted in the regulars.

*Walter G. Aurand.*

## NEW YORK CHAPTER

The January meeting of the New York Chapter was held on Monday evening, January 16, in the Merchants' Association Rooms in the Woolworth Building, and was known as Steel Salesmen's Night.

Three principal speakers were scheduled to present papers covering certain of their experiences in the selling of steel. The speakers and the titles of their papers were as follows:

D. G. Clark of the Firth-Sterling Steel Co., "Your Money's Worth." J. H. Roberts of the Edgecomb Steel Corporation, "What a Steel Salesman Thinks About." A. W. Minuse of the Central Alloy Steel Corporation, "Necessity for Close Association Between the Salesman and the Production Man."

Mr. Clark defended the practice of spending large sums to develop, introduce and advertise new steels, saying that the large price which the first users necessarily had to pay in order to cover these extra promotion expenses was justified because these new users got much higher returns than any who might later be attracted by the merits of the new steel and make use of it at a lower price. He also approved of the sale of fine steel under specification, but only on the basis that the specifications be regarded as covering the minimum requirements and only if the user thoroughly understood that the specification will make it more difficult and more expensive to introduce improved types of steel, so much better in performance that they would fall without the limits of the standard specification then in use.

Mr. Roberts spoke on the subject, "What Steel Salesmen Should Think About" rather than the subject as shown. His principal point was that a salesman must find time to learn the maximum amount about the steel he is selling and the individual problems of each customer. Mr. Minuse called attention to the fact that the salesman and the production man of the same company ought to be closer together, if only for the fact that the salesmen are able to dig up new demands for the company's materials.

Formal discussion lasted for about 45 minutes and informal discussion after adjournment for about one hour.

This is the first session which the New York Chapter has devoted to the steel salesmen and was instituted in view of the fact that that class of men had been recently admitted to full membership in the Society. The results justified our expectations.

*E. E. Thum.*

## NORTHWEST CHAPTER

The January meeting of the Northwest Chapter was held at the University of Minnesota. Fifty-four people attended the dinner at the Minnesota Union. W. R. Appleby, Dean of the School of Mines and Metallurgy and Director of the Mines Experiment Station, was to have outlined the

field of work of the Mines Experiment Station and the North Central Branch of the U. S. Bureau of Mines, but at the last moment he was unable to attend and Thomas L. Joseph, superintendent of the North Central Branch of the U. S. Bureau of Mines talked to those at the dinner regarding the cooperation of the two stations and some of the work of the Bureau.

In connection with their researches on the blast furnace, Mr. Joseph pointed out that largely as a result of their researches one company had modified their blast furnace practice and had reduced their coke consumption ¼ ton per ton of metal produced. If the same economy could be accomplished in all of the blast furnaces in this country a saving in coke amounting to more than 10,000,000 tons annually would be effected.

Mr. Joseph also discussed the work which they were doing on the manganese investigation, particularly with reference to the utilization of the manganiferous ores from the Minnnesota mines.

The meeting then adjourned to the Mines Experiment Station where Edward W. Davis, superintendent of the station, explained the work which they are doing, particularly with reference to the direct reduction of iron ore. The members and guests were then shown through the laboratories where they observed an experimental blast furnace with its capacity of about ten tons per day, the furnace used in the direct reduction of iron ore, the open-hearth furnace used in the production of steel from the metallized iron, a small Bessemer converter, and the experimental open-hearth furnace used by the Bureau of Mines in their researches on manganese.

This experiment station is one of the best in the world for the work for which it was planned. It was at this experiment station that a successful method for the concentration of magnetic ore was worked out. The station plays an important part in connection with Minnesota ore resources. At the present time nearly half of the ore which goes down the Great Lakes has been beneficiated in some way and much of the experimental work leading to the best methods of treating the ore has been done at the school of mines experiment station. The supply of high grade ore in Minnesota will last only for comparatively few years; on the other hand, if the low-grade ores can be used the supply is adequate for many years.

*O. E. Harder.*

## PHILADELPHIA CHAPTER

The Philadelphia Chapter held its regular monthly meeting on January 27 at the Engineers' Club. The dinner preceding the meeting was attended by eighty members and guests of the chapter. The meeting was called to order at eight o'clock, and it was found that more than two hundred persons were on hand.

There was very good reason for this turnout, for the speaker of the evening was that venerable and distinguished metallographist and teacher, Dr. Albert Sauveur.

The business part of the meeting was short and dealt chiefly with a review of the Chapter's activities during the first half of the year 1927-28. This review was presented by lantern slides and showed the financial status of

the chapter as regards to its Year Book, the annual smoker, and the membership. There was a somewhat discordant note sounded as regards the loss in membership which the chapter has sustained, but it is believed that the situation is being met not only in securing new members, but in the excellent work being done in re-instating some who have been dropped for various reasons.

The speaker of the evening, Dr. Sauveur, chose for his topic "Steel and Its Crystallization". He was introduced by an old friend and enthusiast, Mr. Coxe, of the Midvale Company. Mr. Coxe briefly reviewed his first meetings with Dr. Sauveur and some of the work done by him.

The first part of Dr. Sauveur's talk had to do with the X-ray analysis of steel as now being carried on, and his explanation worked out on a blackboard as to the various phases of the iron atom, etc., certainly clarified for many, some of the haze usually surrounding such subjects.

The second part of his talk, which was beautifully illustrated by lantern slides, had to do with the theory of hardening of steel. This discussion left an impression, which will not be readily forgotten in the Philadelphia Chapter. As one member stated, "Here at last was something that even the high-brows chose to remain silent about, rather than openly discuss". Dr. Sauveur's main point was built about the nature of the animal Martensite. His discussion of saturated solutions, super-saturated solutions, transitions, etc., left most everyone so much food for thought that there were naturally some cases of mental indigestion. Some of this ailment was cleared up in the discussion which followed the paper.

The talk was by far one of the finest it has been the privilege of the chapter to have heard. It is recommended that other chapters able to secure Dr. Sauveur for their speaker should be prepared to listen with open minds to his discussion. Only by so doing will they appreciate the detail of his explanation. And, it is suggested that as many chapters as possible should have this wonderful metallurgist on their programs during this year at some time.

*Arthur W. F. Green.*

## ROCHESTER CHAPTER

The regular January meeting of the Chapter was held at the Hotel Osburn with thirty members and guests present at the usual informal dinner which preceded the meeting. After the dinner and a short business session our chairman, G. C. VanVechten, introduced the speaker, Dr. Enrique Touceda. The speaker pointed out that malleable castings have been used in machine parts for many years, and there are no difficulties in getting high tensile strength, but machinability is what is demanded. A customer will complain on hard iron and recall old days when material was easy to machine, but in old days fifty feet per minute was satisfactory, while today three hundred feet is what production requires which makes up for usual complaints. The average yield point is 36,000 lbs; 40,000 is unusual. Dr. Touceda reviewed the history of malleable iron manufacture and then discussed the more modern methods of its production. The speaker illustrated his paper with stereopticon slides showing many types of good and bad microstructures of malleable iron and described wherein these structures gave good or bad results.

The meeting adjourned with a rising vote of thanks to Dr. Touceda.

*H. J. Leclaire*

## SPRINGFIELD CHAPTER

The Springfield Chapter of the American Society for Steel Treating held a joint meeting with the Engineering Society of Western Massachusetts, Tuesday, January 17, 1928. The members and guests of both societies visited the plant of the Springfield Gas Light Company in the afternoon. Guides were provided by the Gas Light Company to escort the party on the inspection tour. A dinner meeting was held later in the Highland Hotel. Mr. Hall, of the Gas Light Company, further enlightened the group with a brief description of the plant and processes seen earlier in the day.

The speaker of the evening was Floyd W. Parsons, editorial director of "Industrial Gas", and writer for about twenty other publications. This technical "Jules Verne" took us back into ancient history, and with rapid-fire output outlined the high lights of scientific achievements, up to the present age. He remarked that since man began thinking for himself, searching for truths, analyzing things and getting the correct answer to problems, that nothing is impossible if the need for it is great enough.

His talk was exceedingly interesting, frequently sprinkled with stories that took. While his speech was delivered in more or less of a light vein, nevertheless there was plenty of food for thought. Mr. Parsons, an engineer by virtue of his training, did not deliver his subject in the cut and dried manner so frequently done at technical gatherings. He kept his audience on their toes, wide awake and eagerly awaiting his next words. *T. C. Kerr.*

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Mr. Thomas Nelson of the Chrome Alloys Products Company, Conshohocken, Pennsylvania, was the speaker at the monthly meeting given by the Springfield Chapter, January 16th, at the Chamber of Commerce Building, his subject being, "Chromium-Iron Alloys". This was a subject he was well equipped to speak on, as he was associated for several years with Mr. Harry Brearly of Sheffield, England, who made the first investigations on chromium-iron alloys at the instigation of the British government which was seeking a new gun metal having the great abrasion and heat resisting qualities necessary to maintain the accuracy of the bores of big guns.

Much work was done with the co-operation of two large steel concerns in England with which Mr. Brearly was connected, and many types and combinations of metals were considered; but finally chromium alloys received all the attention, although they were not used except experimentally in the capacity for which they were originally intended.

Mr. Nelson said that a Sheffield cutlerer visiting him at the plant one day noticed material lying around in the yard that had not rusted, and suggested making kitchen knives of it. This was done, and, though the first rustless steel knives could not be compared with articles produced today, it was a great step forward in the great stainless steel industry of the present time.

But, it was not as simple as it seems; many discouragements were encountered. Some material of like chemical analysis was tried out and found not to be rustless at all, or so brittle that a slight blow would shatter it. How-

ever, the type that promised to give the best results was a chromium-iron alloy with approximately 16 to 18 per cent chromium, as this class was more amenable to heat treatment than the higher chromium alloys.

From these small beginnings, Mr. Nelson has seen and supervised the installation of immense chromium-iron units in chemical and other industries where failure of material would mean great loss of life and money. He showed a series of lantern slides illustrating this and other features of this talk.

*T. P. Jones.*

## ST. LOUIS CHAPTER

The seventy-second regular monthly meeting of the St. Louis Chapter was held Friday evening, January 20, 1928, at the American Annex Hotel. The meeting was preceded by the usual get-together dinner with an attendance who braved the cold weather, and the officers as a whole will be stimulated to greater efforts to make the St. Louis Chapter a bigger and better one.

The executive committee has decided to double the membership, by having inaugurated a membership drive. There were two teams appointed, the blues and the reds. L. T. Clarke of the Leschen Rope Company is captain of the blues, and C. A. Carlson is captain of the reds. The prize for the winners will be announced when the contest is ended, and we look forward to an interesting campaign. As a high private in the rear ranks of the red army the writer intends to make the opposing blues see red—this is not a promise, but a threat. The blues have drawn blood in the first round, but the reds took the second round.

R. M. Pease of the Axelson Machine Company was appointed chairman of the welcome committee and O. R. Moody was appointed chairman of the entertainment committee, and we look forward to some good times.

After the short business session Dr. N. B. Hoffman of the Colonial Steel Company addressed the chapter by an illustrated discussion of general metallurgical terms as applied to both carbon and high speed tool steel. That Dr. Hoffman took the kinks out of a lot of the technical terms was apparent from the many favorable comments. After the slides were shown the speaker sat down close to his audience and an interesting discussion was had by all. We felt sure all who were in on this address and discussion were well paid for their time. The meeting was adjourned with a standing vote of thanks to Dr. Hoffman and his company for this appearance before our chapter.

*C. G. Werscheid.*

## WORCESTER CHAPTER

The February meeting of the Worcester Chapter was held at Rebboli's Restaurant on Friday, February 3. The meeting was opened by Mr. Bigelow, who announced that the subject for the evening's discussion was to be the hardening of high speed steel.

Mr. Searle, who was assisted by other members of the local chapter both in the collection of data and its presentation, gave a very instructive outline of the methods of hardening high speed steel with particular reference to the use of a lead bath at high temperatures.

The details of the paper and its discussion are to be placed in printed form for further presentation.

*R. C. Jordan.*

# Items of Interest

T. D. LYNCH, past president of the A. S. S. T. and vice-president of the A. S. T. M., has been promoted from chief of the materials and process department to that of consulting metallurgical engineer with the Westinghouse Electric & Manufacturing Company, East Pittsburgh. Mr. Lynch will devote all of his time to metallurgical problems both ferrous and nonferrous and may be addressed at Room 7-N-44, Westinghouse Electric and Manufacturing Company, East Pittsburgh.

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The Brown Instrument Co., Philadelphia, announces the new Brown flush type continuous chart recorder, a simple but important feature of which is an arrangement by which the recording mechanism can be drawn out of the case at the front for easy inspection, after which it can be pushed back into place, a locking device holding it firmly in position.

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E. C. Black, formerly metallurgist for the West Michigan Steel Casting Co., has accepted the position of metallurgist with the Edward Valve Co., East Chicago, Ind., manufacturers of high pressure and temperature valves.

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Technologic Paper No. 358, Air-Hardening Rivet Steel, has been published by the Bureau of Standards. The author is H. K. Herschman, assistant metallurgist. This paper contains the results of tests on a series of alloy steels to determine their applicability for rivets that would have a ballistic resistance at least approaching that of the armor plate they joined. This pamphlet may be obtained from the Government Printing Office, Washington, for 15 cents.

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The Sheet Steel Trade Extension Committee, Oliver Bldg., Pittsburgh, have issued a booklet, "Steel Roofing—Its Use and Applications."

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"The Truth About Anti-Friction Bearings," is the title of a small illustrated pamphlet prepared by the Timken Roller Bearing Co., Canton, Ohio. This discusses the advantages of the Timken-type of tapered roller bearings.

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The Buyers' Guide of nickel alloy steel products is now available from the International Nickel Co., 67 Wall St., New York City.

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The Bristol Co., Waterbury, Conn., has for distribution a new catalog No. 1502 describing and illustrating the Bristol line of recording wattmeters and recording frequency meters.

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J. W. Rockefeller, Jr., formerly with John Chatillon and Co., is now consulting engineer, located in the Woolworth Bldg., New York.

*(Continued on Page 36 Adv. Sec.)*

*THE*

# TRANSACTIONS

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RAY T. BAYLESS, *Editor*

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